AN ECONOMIC PRIORITY MODEL FOR RURAL HIGHWAY IMPROVEMENTS

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BY

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JHRP

JOINT HIGHWAY RESEARCH PROJECT
PURDUE UNIVERSITY AND
INDIANA STATE HIGHWAY COMMISSION

Final Report

AN ECONOMIC PRIORITY MODEL FOR RURAL HIGHWAY IMPROVEMENTS

TO: J. F. McLaughlin, Director
Joint Highway Research Project

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

Project No.: C-36-73D

File No.: 3-4-4

December 3, 1970

Attached is a Final Report titled "An Economic Priority Model for Rural Highway Improvements" on the research Plan of Study titled "Priority Programming for Highway Construction" that was approved by the Advisory Board on September 18, 1969. The research was conducted and the report authored by Mr. Salim S. Fejal, Graduate Instructor in Research on our staff. Professor H. L. Michael served as director of the research project.

The research reported includes the development of an economic model which provides the highway planner with priorities of construction projects based on their economic merits. The model was applied to that portion of the Indiana state rural two-lane highway system not now programmed for improvement and a priority based on economic merit is provided for each such highway as of 1970. The resulting high-priority projects in each ISHC District were found by field review to be badly in need of improvement.

The report is presented to the Board for acceptance. It is hoped the models and the techniques developed will be useful in the programming process of the ISHC.

Respectfully submitted,

Harold L. Michael

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by

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ABSTRACT

Hejal, Salim Said. Ph.D., Purdue University, January 1971. AN ECONOMIC PRIORITY MODEL FOR RURAL HIGHWAY IMPROVEMENTS. Major Professor: Harold L. Michael.

Priority Programming is a first step in the process of scheduling construction on the basis of factual needs by allocating highway funds using a priority system. This operation is instrumental in translating construction warrants into capital budget while insuring optimum return for the funds invested. Most existing procedures employ one form or another of sufficiency ratings. The very arbitrary nature of empirical rating coupled with the inherent weaknesses of a ratings scale makes it doubtful whether any rating formula can ever satisfy all conditions affecting priorities. In many states the results of the sufficiency rating surveys are seldom used in the programming decision process. Decisions are based on other factors, many of which could be translated into monetary terms while sufficiency ratings cannot.

The purpose of this research was to develop an economic model that would provide the highway planner with suggested construction projects whose priorities were based on their economic merits. Quantitative measurements were sought for each factor and a dollar value was determined for many of the items involved. The results of the quantification process were then employed in the economic priority model constructed. A benefit-cost ratio analysis was employed in the final

discretion between improvement alternatives at the same site (section) and as the priority rank for the various sections.

The success of the proposed method was conditional to the quality of the quantification process. A procedure for calculating road user operating costs was devised; it made use of a travel time predicting model for two lane highways which had been developed by this research. Accident costs were estimated by employing the results of a comprehensive accident study of rural state highways which had been conducted by this investigation. While road user costs estimate highway benefits, capital expenditures form the basis for highway cost in the benefit-cost ratio analysis. A detailed study of capital expenditures for highway construction on Indiana rural state highways was conducted. Regression models estimated the costs of the four major highway construction activities: roadway construction, roadway reconstruction, roadway maintenance and bridge construction.

With the various components of the proposed economic priority model formulated and the cost elements and decision parameters evaluated, the technique was applied to the Indiana rural state highway system. A computer program was prepared for this purpose and the digital computer was used for the analysis. The results of the application were verified by field checks.

The economic priority model using the benefit-cost ratio analysis is a simple, reliable and practical method for the evaluation of programming priorities. This approach is logical, conceptually sound and a pioneering attempt to quantify all the elements of the priority decision process.

CHAPTER I. INTRODUCTION

The need for planning is recognized in almost all the activities of todays complex society and in the field of public works is a must. Some of the desirable characteristics of planning procedures and results are providing of new facilities when and where they are needed, coordinating and directing the flow of transactions through the maze of governmental and private agencies, and insuring the proper allocation of limited resources, such as manpower and money.

The growth in population and the expansion in economy coupled with an ever rising standard of living continually necessitate actions such as building of new highways, providing more hospital beds, training more teachers, etc. An ideal planned environment would match the growth with its requirements. For many reasons however, required items that are needed today were not produced or even planned. The results are congestion, over-crowding and public complaints. There is, therefore, a backlog of improvements which must be added to the replacement of existing facilities that wear out.

The governmental structures through which planning activities are accomplished are complex, overlapping, competing, contiguous and have unbalanced revenue systems. Any expenditure of public funds typically required to be justified, approved by more than one branch of government and matching funds from one or more sources must be on hand. This is a process that takes time and effort and cannot be accomplished on the spur of the moment.

The available resources, whether manpower or money allocated to public works, are very limited. Although our economically affluent society has generally increased the sources and amount of public funds, it has also generated heavy demands for expenditures. These demands have resulted in fierce competition between political bodies, geographic regions and population groups for the tax dollars. Public highways are a stereotype of this planning problem.

Highway planning is a continuous, orderly process of collecting information, analyzing it and recommending efficient and economic development of the highway system. Planning is the first step in achieving the objective of adequate highway system, best stated as the development of a highway network capable of accommodating all the highway travel demand within acceptable levels of service. Level of service is used here as an aggregate descriptor of safety, convenience, economy, etc.

The highway planning process, discussed in more detail in Chapter III, measures the needs of the system by a needs study. Following a needs study, fiscal planning provides legislators with guidelines for future taxation. Then, on the basis of forecasted revenues, a general improvement program is developed for a time period. At the end of the program the highway system is expected to be operating at an acceptable and desired level of service. The time period, defined as the catch-up period, usually ranges between 15 to 25 years.

Not all needs can be met at the beginning of the program period, and the intriguing problem of deciding what and when to build is the task of priority programming. A well constructed priority system,

based on factual needs, is instrumental in translating construction warrants into capital budget to match flow of revenue with flow of work while insuring an optimum return for the funds invested. Priority programming is not an easy task; it has developed slowly during the past two decades and the state of the art is yet to mature.

By the end of World War II, state highway departments all over the nation began facing the problem of inadequate highways. The magnitude of the problem, something they never experienced in the past, was brought about by the absence of any significant construction or improvement programs during the war period. At the same time, many highways were subjected to loads and repetitions for which they were not designed. The need for better highways was urgent. Within a decade, travel on these highways, measured in vehicle miles, had nearly doubled and needs simply had to be backlogged. Highways, however, were not the only government responsibility that required immediate and considerable amount of resources for other agencies and services were competing for available government money.

Faced with this situation, highway commissions found it wise to choose the most needed projects to be scheduled first. To do this they not only had to define what was most needed and what was not, but among those projects which were critically needed a choice had to be made of those that were to be funded. Some states conducted public hearings as part of the process of deciding on what projects should be scheduled for construction. To the majority of people, the most important highway is the one passing their property, and most hearings were colorful and noisy. Political pressure often resulted and decisions on construction

projects seldom met with overwhelming approval. The need for better methods was obvious. The answer was found in the use of more scientific highway planning.

It was the late forties and early fifties when highway planning started moving from the state of a mystic art into the realm of science. In the latter period, terms like highway needs, highway inventory, traffic studies, fiscal studies and highway programming were established and became part of the methodology of the planning practice. Priority programming is another link in the chain of highway planning. A well known method, the sufficiency rating, was founded in Arizona in 1947 and within twenty years it was estimated that 90% of the states in the Union used one form of the sufficiency rating or another.

Sufficiency rating systems were devised by various agencies and many were successful in minimizing the element of personal judgement. They usually met with the approval of public and legislative bodies. But twenty years have passed since the introduction of sufficiency ratings and while more scientific management tools have evolved in many areas of highway planning, highway programming using the sufficiency rating as a priority tool has exhibited little progress. In many states the results of a sufficiency rating study are seldom used in the decision making process. Decisions are based on other factors, many of which could be translated into monetary terms while sufficiency ratings cannot. Availability of Federal funds, maintenance costs, accidents, etc. are examples of these factors. Some of these are nested within the sufficiency rating scoring items but many are not assessed in the rating procedure.

In the literature, numerous articles and papers point out the weakness of the present system and suggest that there is room for research and improvement. In 1960 Johnston (34)* proposed the following argument:

> "Today, highway planners are seeking more scientific methods of evaluating existing highways and designing and programming new facilities. The highway administrator and planner realize as never before the importance of engineering tools that will permit them to schedule construction on the basis of need, allocate highway funds on a priority basis, select additions to the highway systems, change system classifications, select proper alternate routes or locations, and to cope effectively with public and private groups having vested interests in the process of planning and programming.
>
> Some States have employed sufficiency ratings to assist them in accomplishing these objectives. This method simply assigns a point rating to each section of road according to its ability to provide traffic service in a safe and efficient manner. Other States have employed economic analysis using factors such as highway costs, revenues, and benefits. In the main, this approach has been simplified to include only the benefit quotient which reflects primarily a savings to the motor-vehicle user in operating cost and time through improved alignment. Some States use both approaches.
>
> In the methods generally is use, one important factor is too often omitted - traffic accident rates. Some States incorporate accident rates in their sufficiency ratings, but more do not. It is known that sections of highway having a good adequacy rating, as provided by the sufficiency rating system, sometimes may have a high traffic accident frequency.
>
> Traffic accident rates normally are not included in economic analyses of the cost-benefit variety at all. The principal reason for the omission has been the unreliability of traffic accident data. Too many accidents are not reported; and for those that are, the reports often do not clearly indicate where the accidents occurred. But one of the greatest deterrents has been the lack of information on accident costs related to the types of vehicles, classes of highways, roadway features, types of accidents and severity of accidents.
>
> Traffic accident data should be one of the highway planner's most important tools to justify street and highway improvements."

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*Numbers in parentheses refer to sources listed in the Bibliography.

Ten years later the presented argument is still valid and the research reported here was addressed to the better assessment of highway improvement priorities.

The purpose of this research was to develop an economic model that would provide the highway planner with suggested construction scheduling priorities based on the economic merits of the projects under consideration. Quantitative measurements rather than subjective judgements were sought for each factor and a dollar value was determined for many of the items involved. These values were then used in the economic model constructed. A benefit-cost ratio analysis was employed in the final discretion between improvement alternatives at each improvement site and among the various sites.

The Indiana state rural highway system was used for data collection, models testing and finally results application. In addition to developing a tool that will aid in the selection of the projects to be scheduled for construction or reconstruction on an annual basis, this research dealt with topics for which few published results were available. Unit costs for different classes of accidents and travel times on rural highways based on physical and traffic parameters are two of these topics. Regression models to estimate maintenance and construction costs are two others. In reality, the range of application of the results of this research investigation cover many aspects of highway engineering practice.

CHAPTER II. REVIEW OF LITERATURE

Historical Background

The use of scientific methods to assign programming priorities of highway construction is a recent phenomenon. In the years following World War II a need arose for defensible priorities that could withstand the various public pressures. The heavy war traffic left the nation's network of roads all but ruined; this coupled with an ever increasing ownership and use of motor vehicles created a great public demand for better highway facilities.

The highway administrator, faced with inadequate financial resources and a public clamoring for improvements to higher standards, had to find some means of reducing these requests to a common denominator where an order of priority could be arranged. Such a tool, the sufficiency rating, was developed in Arizona and has been used successfully since 1946. The system filled a need for a reasonable and logical manner of allocating funds for highway improvements. Described by one author as a most satisfactory, realistic, and factual means of evaluating highway needs and programming improvements (36), the sufficiency rating procedures have been adopted by the majority of the states and the Federal Highway Administration.

Sufficiency Ratings

A majority of states assert they use sufficiency ratings in determining the priority of their highway needs. Some believe that

sufficiency ratings lifted highway needs evaluation from the realm of speculation to a position of actual analysis. The formulas and procedures have been devised with the intention of minimizing the elements of personal judgement in determining the relative sufficiency of highway sections. In general, the basis for the rating is an assignment for a perfect road of 100 points divided among the following three major criteria of approximately equal weight:

1. Structural conditions; some of the items that are included by different states are structural adequacy for different components of the pavement, anticipated remaining life, maintenance economy, etc.
2. Safety; this is measured through design elements such as roadway width, surface width, stopping sight distance, intersectional friction, consistency, etc.
3. Service or function; items like alignment, passing sight distance, intersectional friction, consistency, etc., are used as measures of this criteria.

Some agencies, however, use different criteria. Ohio uses capacity as a third factor and lumps service and safety into one factor (45). Many states modify the rating criteria and use separate tabulations for each highway system classification. It is usually believed that the sufficiency rating procedure provides a means of evaluating the adequacy of each section of a highway relative to certain prescribed standards. Averaging the ratings over the entire state for the highway system on a yearly or biennial basis, therefore, indicates the rate of progress of the highway long range improvement program. It is also very easy and

clear to convey the highway needs problem graphically when sufficiency ratings are used.

Sufficiency ratings were accepted because they filled a need for allocating funds based on priority. Yet the ratings often leave a lot to be desired. The ratings used by different states are tailored to fit the conditions existing in the pertinent state. When Swanson (53) compared results of 16 states rating procedures on four typical sections of highway, the results were inconsistent. He found that the lower the ratings of a section the greater were the deviation and relative dispersion of the results. In other words, the rating formulas were consistent on the better road sections but showed wide differences on the poor ones. This emphasizes the fact that the assignment of arbitrary weights to the different components of a rating system may result in manipulations in such a way as to give a high priority to any desired project.

Critics also note that the addition of the rating values for the different criteria can produce a high final rating that does not reflect a much below standard condition in any one of the three criteria. A dusty dirt road that is expensive to maintain, for example, could still achieve a total rating of 70. Such a score would place the section in a low priority bracket in most states. To counter this, some states set a minimum allowable score for each of the three criteria below which a critical deficiency is recorded no matter how high the final score. This does not eliminate the weakness that sufficiency ratings are not sensitive to critical items, and makes the problem of assigning priorities difficult. For one is then forced to make a decision out of

the context of the ratings - which project is more urgent, a section with a total rating of 62 or a section with a rating of 73 which has a very critical structural condition. This minimizes an advantage of sufficiency ratings - that priority decisions can be made on the total rating of the highway. Campbell (4) suggests the use of a three digit index as a substitute for the total composite rating in order to expose critical deficiencies. Such an index would indicate a rating for each of the three elements (structural, safety and service). Once again, deciding between a section with a 1-3-8 rating and another with a 2-2-8 must be done out of the context of numerical rating.

The very nature of the arbitrary assignment of weights raises doubts as to whether the sufficiency rating procedures actually measure relative sufficiencies. For example, passing sight distance opportunity, an element often incorporated in the ratings, is not an objective relative sufficiency measure unless related to the volume of traffic using the highway. Most proponents of rating systems also acknowledge the need for considering many factors in addition to those which can be incorporated by rating formulas. Programming of funds for the construction of new routes, for example, must be done with the aid of special studies and out of the context of rating systems.

Sufficiency rating procedures are also often not suited for both rural and urban areas. Many states as a result have two different rating systems. Others gave up completely on the idea of being able to rate urban arterials (21). Furthermore with the present rating systems, rural highway intersections and interchanges are very difficult to rate, though many times these are deficient elements of the system.

Rating methods were tested in Phoenix and Nashville (27) and the following findings resulted:

1. Ratings are not sensitive to the values of weights given to different criteria.
2. Rating formulas do not properly consider the existance of a parallel facility of a higher type. Rating formulas, similarly, do not take into account future construction of parallel facilities. People tend to tolerate facilities that are inadequate if a better parallel facility exists.
3. Drivers tend to tolerate a bad section of a short length when everything else is of high type, while a rating formula might assign a low priority that does not reflect the judgement of the public.
4. Sections used for ratings do not correspond to lengths of construction projects.
5. Any rating process does not indicate the need or give any priority to a needed new route.

For these reasons and many others, it is an accepted fact that sufficiency ratings are not the only criterion for selection of construction projects in highway programming. Many states reformulated their programming procedures to account for other factors. Some agencies, however, developed brand new priority systems.

Other Rating Systems

Three rating systems - used in Minnesota, Tennessee and Pennsylvania - are innovative and interesting.

Minnesota (53)

Considerable effort was devoted to developing a suitable means of programming construction needs in a continuous and up-to-date orderly basis in Minnesota. Three factors were considered for evaluation of such needs. These three factors were not combined into a single numerical rating, but a separate listing of deficient highway sections was made for each factor. With this system, a road section badly deficient in only one area was assigned a high programming priority when the three listings were examined simultaneously.

The first factor measured the ability of a road to carry its traffic and was compared with similar sections. For rural highways, a congestion index, the ratio between the thirtieth highest hourly volume and the practical hourly capacity was used to measure this factor. The thirtieth highest hour was estimated from traffic survey data, while the practical capacity was computed in accordance with the procedures of the 1950 Highway Capacity Manual.

The load carrying capacity or structural adequacy was the second factor. In Minnesota the highway system is subject to severe loss in load carrying capacity each spring. A comparison of the bearing test results in the spring with designated tolerable standards of load carrying ability formed the measure used for the second factor.

The third factor rated the condition of the highway section. The relative magnitude of the average annual maintenance cost quantified this factor.

It is difficult to compare the Minnesota formula with other rating procedures. Though three important factors were measured objectively in this method the final programming decisions were made subjectively by examining three separate lists of deficient conditions.

Tennessee (14, 15, 25)

In 1956 the Tennessee Department of Highways and Public Works co-operated with the Automotive Safety Foundation in developing a priority rating method and procedures that were used in formulating a five year construction program. A campaign to explain the program to the public was rewarded with a reported solid acceptance. The rating method for rural highways chose three criteria as basic and significant in measuring deficiencies. These were dependability or structural condition, facility of movement and safety.

Highway dependability was measured by appraising the various components of the pavement system. A single factor combining the rating of various factors was further reduced to a one digit index. A perfect pavement would have an index of zero while the worst possible score was nine.

Facility of movement was chosen to measure the degree by which existing road and traffic conditions deviate from design or desirable standards. Using the Highway Capacity charts developed by O. K. Normann, the average of two differences (standard design speed minus actual average design speed and standard operating speed minus the actual operating speed) was weighted by the average daily traffic of the highway section being rated. When all the sections of the highway system were rated, the results were arrayed in descending order of the

quantity just defined and then grouped into ten approximately equal groups. The sections in these groups were given index numbers nine to zero. This digit was entered as the second of the section's 3-digit priority index.

The number of accidents per mile on a section in 1955 was rounded to form the safety rating and used as a third digit in the section 3-place index figure. Fortunately, no section reported more than ten accidents per mile; thus a ready made scale of one digit was possible.

The deficient sections were divided into five classes based on a scoring system that appraised the section conditions rated by the 3-place index. The scoring system placed more emphasis on dependability, facility of movement and finally safety, in that order.

The rating procedures of the three individual criteria and their reduction into a one digit index was as arbitrary and defenseless as in classical sufficiency ratings. The same empirical weaknesses could be justifiably raised. The final scoring system that arbitrarily placed more emphasis on structural deficiency would be difficult to justify. It was based soley on the personal judgement of the individuals who devised the system.

In rating urban sections, vehicle delays at signalized intersections were used as the measure of the facility of movement criterion. The average seconds of delay per vehicle for the highest hour plus that in each successive consecutive hour, if any, was determined using highway capacity data and some reasonable assumptions. Such delays for all signalized intersections within the section under study were totaled. The average delay per mile per section was then calculated and was the

factor considered in the programming of signalized urban route improvements.

Pennsylvania (21, 22)

An interesting approach to resolve the difficulties and drawbacks of sufficiency rating procedures was attempted in Pennsylvania. The procedure converted deficient structural conditions and/or functional plight into a measurable economic entity. A relative partial measure of benefits achieved by reconstruction were compared to the estimated cost of improvement. The resulting modified benefit cost ratio was used as an indicator of the need for improvements.

In this method, either of two conditions, structural or functional, could render a road section obsolete, and the dates of such obsolescence could be estimated. The structural retirement date of which the pavement would require reconstruction is found from survivorship curves of road life studies. The functional obsolescence date, defined as the date when forecasted traffic volumes will equal the capacity of the highway section at desirable operating speeds, is more complex to determine. Desirable operating speeds, for example 50 mph on flat terrain rural highways and 30 mph for city streets, were used to compute the corresponding 'capacities' of road sections in Pennsylvania. In this method, capacity is defined as the number of vehicles that the road section will pass at the desired operating speeds. When desirable speeds are unattainable due to traffic or roadway conditions, congestion is identified. Road sections that are operating below the desirable speeds for some or all hours of the day have reached their functional obsolescence date. Once obsolescence is identified, the congestion

delay cost is estimated and totaled annually for each highway section by a well detailed procedure developed for this work.

The two obsolescence dates are most often separated and a decision must be made as to which date is to prevail. The following example will clarify the Pennsylvania rationale. Suppose a road section should be structurally retired in 1973 but will not be functionally obsolete until 1980. Should the road be resurfaced in 1973, and, assuming a 15-year life expectancy, suffer congestion between 1980 and 1988? Or should it be reconstructed in 1973? Reversing the above dates, suppose the road will be functionally obsolete in 1973 and structurally retired in 1980. Should congestion be tolerated for seven years, or should the road be reconstructed in 1973, thus losing seven years of structural life?

The answers for these questions are provided by an economic analysis using the modified benefit-cost ratio. The road sections are tabulated by years of obsolescence and in descending value of this ratio. Present and long range programs are then a matter of examining these tables and choosing the most needed projects. The system just described was handled in Pennsylvania by electronic data processing. In so doing, considerable use of averages and short cuts was justified by the author. More fragile flanks in the approach are the following:

1. Arbitrary use of a desirable speed for computing congestion costs,
2. Ignoring completely the factor of safety and the use of accident costs in the economic analysis,
3. Ignoring the motor vehicle operating costs in computing the user benefits,

4. Considering construction alternatives that would bring operating speeds only just above the desirable speeds,
5. Ignoring the problem of right of way that might arise with construction improvements.

These weaknesses should not obstruct the fact that the Pennsylvania approach appears to be one of the most objective, rational and intelligent priority rating methods presented in the literature.

Present State of the Art

In 1962 a survey of scheduling procedures of state highway departments was reported by the Highway Research Board Committee on Highway Programming (8). The responsible personnel in 31 states were interviewed as to the basis of their project selection for construction programs. The following summary ignores the fact that programming decisions once made are not firm, and that many revisions do occur for many unspecified reasons. The 31 states reported:

a) In 25 states the district engineers select the projects for the work programs; of these, 16 use sufficiency or other types of rating formulas with four (4) of the states adding a personal judgement factor. The remaining nine (9) states indicated that personal judgement of the district engineer was their basis for project selection.
b) Four (4) states select projects at the central office; two (2) of these use the sufficiency ratings and the other two (2) use general data and largely personal judgement.
c) Surprisingly, the remaining two (2) states reported no specific procedure!

Since the date of the above study, little has been done in the field of construction project priorities. The literature search did not uncover any significant new developments. Research attention in the general area and the bulk of papers reported since 1962 are in the field of programming.

After the priorities have been set and the projects for the capital improvements program have been selected, the next steps in highway planning are programming the preliminary engineering, right of way planning and acquisition, construction scheduling, etc. Grunow (26) suggested the use of PERT to co-ordinate highway management activities. Reed and Futrell (48) demonstrated the use of CPM, RAMPS and RPSM on multiple scheduling of preconstruction engineering activities. More recent work proposed the use of dynamic programming to schedule highway construction projects under a given budget while maximizing benefits (44). Unfortunately, progress in the programming field has little bearing on possible advancement in priority determination. The two steps are very much related but techniques developed in one are of little use in the other due to the different tasks involved.

It is doubtful whether any formula can ever satisfy all conditions affecting priorities. A priority system, however, whether sufficiency rating or any other, is not a separate phase of highway planning. It should be part of the highway programming effort. Highway programming, defined (5) as the translation of construction warrants into capital budget to match flow of revenue with flow of work, should be accomplished using a priority system based on factual needs and optimum return for the funds invested.

In addition to the items rated by present procedures, many authors of papers reviewed in the literature stressed that priority programming methods should consider maintenance costs (20, 21, 32), improvement costs (14, 21, 22, 32), a measure of accident experience and/or their costs (14, 20, 52), congestion and delay cost (14, 20, 22, 25, 32) and cost effectiveness of improvements (20, 21, 22). Some of the systems described earlier included some of these measures, but none have included all. The difficulties of including these five factors and/or some arguments for their inclusion are:

1. Maintenance Cost. It is difficult to estimate the maintenance cost of existing highways and proposed improved sections because of:

   a) lack of exact definitions

   b) absence of uniform accounting practices

   c) variation in the standards of maintenance adequacy

   d) poor records of maintenance costs in many states.

   Even with these handicaps, it is recognized as important that maintenance cost be estimated and used in priority determination.

2. Cost of Improvement. Present rating systems do not reflect any estimate of the cost of the improvement. A high priority rating does not mean a low or a high improvement cost. Only a few states include the costs of bringing highway sections to design standards as part of their priority system. The difficulties encountered in estimating the cost of highway improvements are similar to those of maintenance. Present accounting practices and the absence of proper records in many

states make the task of evaluating the cost of various construction components on a unit basis impossible.

3. Accidents. Though sufficiency ratings include a safety criterion that is typically one third of the rating points, very few states incorporate the number of accidents or accident rates as a measure of the safety of highway sections. There are several factors that make this job difficult.
   a) It is very difficult to determine which accidents were a function of highway conditions.
   b) It is very hard to estimate what the accident picture will be after improvements have been constructed.
   c) All accidents are not reported.
   d) Estimated accident costs on accident records are only a partial cost of accidents.
4. Congestion and Delay Cost. Very few states compare traffic volumes on the highway sections with capacities to get a measure of congestion. Though congestion usually is not an apparent important factor on rural highways, the majority of drivers today demand highways capable of providing high speeds and levels of service. The economic utility of achieving higher speeds (lower travel times) on improved highways is worth considering. On the other hand congestion is recognized as important in urban areas, and it is included as a factor in determining urban priorities in a few states.

5. Cost Effectiveness of Improvements. For a highway construction project, several alternatives are sometimes analyzed and the selection decision is based primarily on the alternative which is most effective for its cost. Cost effectiveness is evaluated by the rate of return, benefit cost ratio or the annual transportation cost methods. This concept might also be used in the programming process, a cost effectiveness approach incorporated in the priority system. It is very probable that sections with low sufficiency ratings will not produce the highest benefits or returns for capital spent on improvements. Highways with low traffic volumes often have sections with low sufficiency ratings. It is very doubtful that scheduling improvements on these sections will produce optimum benefits to highway users, those who are paying for the highway program.

In summary, there is need to develop a technique of establishing priorities as an integrated part of highway programming and budgeting and which includes consideration of the above factors.

CHPATER III. CONCEPTUAL FRAMEWORK OF AN ECONOMIC PRIORITY MODEL

Introduction

Government bodies are the public's agent; they furnish the services people desire. Such desires should be reflected in governmental decisions. Transportation planning, in general, and assigning priorities for programming construction improvements, in particular, are examples of such decisions. Before proposing new priority decision tools it would be wise to examine motorists' evaluation of services provided by the highway system.

Access, expediency and safety are their foremost measures of highway service. For the majority of the public the most important road in the state is the one they use daily. Though they are strongly in favor of enforcing twenty miles per hour speed zones on the streets passing their homes, the majority of motorists fancy the thought of freeways built to connect their most frequent destinations. One fact is obvious, the public in general is interested in better highway service, measured by less travel time, delays and congestion.

On rural highways it is an observed fact that operating speeds are rising annually. The extensive mileage of the Interstate system opened to traffic has changed the public's perspective and driving habits. Drivers enjoy using the Interstate and appreciate the higher speeds and levels of service that system provides. It is impossible, however, to operate safely at such high speeds on the remaining highway network. The demand for better highways of Interstate standards is

one aspect of the Interstate's impact. In Indiana, proposed freeways connecting Lafayette to Marion and Terre Haute are examples of such demands and such ideas are often popular news items. Higher levels of service and operating speeds are factors to be reckoned in priority evaluation.

A driver can tell his speed and measure his travel time with ease, but judging the safety (the possibility of accident involvement) of the highway he is using is a harder task. For no matter how high the accident rate of a facility, very few motorists are actually involved in accidents.

The agencies in charge of compiling and analyzing accident records, however, keep the public informed of unsafe highways. The term "Killer Highway" is familiar and every campaign for safety is a popular issue. Hence, although the public as individuals are seldom involved with particularly hazardous locations, collectively they support safety improvement programs.

Not many would argue the hypothesis that the public is interested in better highway transportation with higher levels of service and lower accident rates. The same public, however, is slow to react to the need for financing improvement programs by paying higher taxes. The highway administrator has always had to work, therefore, in the shadow of limited budgets. The capital available for highway construction is a critical constraint that governs the operation of highway departments and it is most critical in the programming phase. Imaginative, progressive improvement programs that cost more than present revenue rates could support have no chance of implementation, and partial

completion of projects could be wasteful. At the priority stage of the programming process maximizing the benefits from a limited budget should be the principal guide-line or the objective function. Projects with large benefits and a high return for investment should receive high priorities.

Systematic Priority Analysis Framework

The discussion highlights of previous chapters are summarized below as guidelines for systematic priority determination of highway construction.

1. Priority analysis is only a step in the programming process. Advance programming is the critical decision making process of highway planning. A flow chart of the planning process is presented in Figure 1; its description is well documented in Wood's Highway Engineering Handbook (42). Any priority system of highway construction is only a guide to the sequencing of needed projects. It serves an advisory role only. The programming process, in addition to identifying needed projects and determining their relative urgency, is involved in co-ordinating the flow of revenues with expenditures. This entails the integration of priority analysis with many other considerations in establishing construction programs.
2. The mechanics of priority analysis should be in harmony and reflect highway transportation objectives.

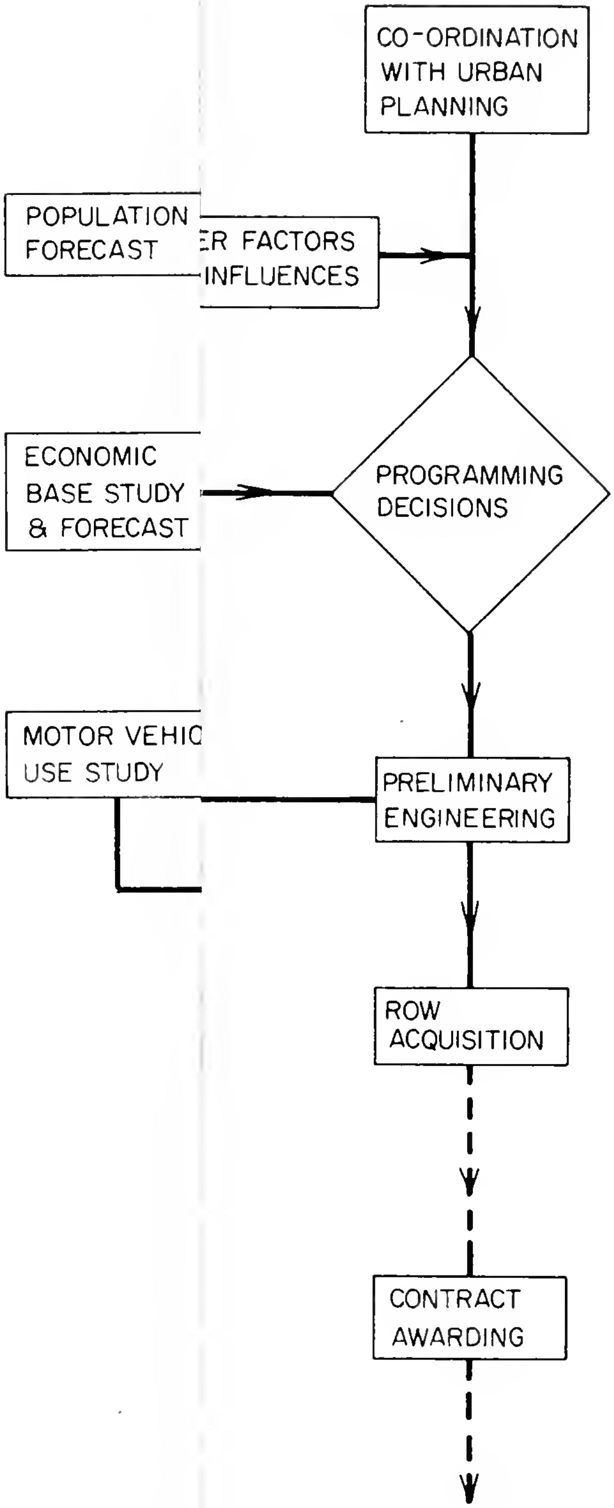
CO-ORDINATION WITH URBAN PLANNING
POPULATION FORECAST
ER FACTORS INFLUENCES
ECONOMIC BASE STUDY & FORECAST
PROGRAMMING DECISIONS
MOTOR VEHIC USE STUDY
PRELIMINARY ENGINEERING
ROW ACQUISITION
CONTRACT AWARDING

FIGURE I. STA

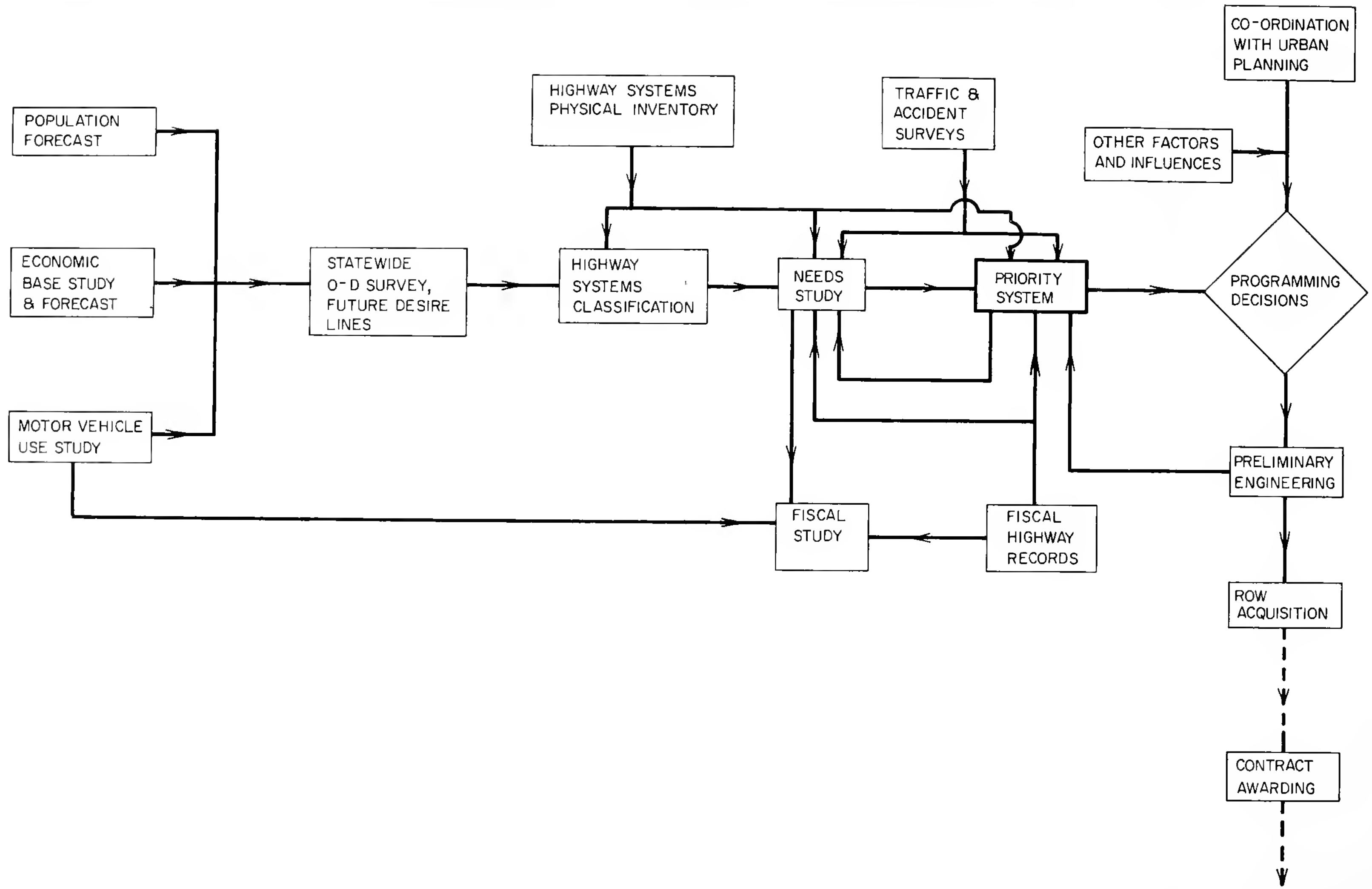

FIGURE 1. STATE HIGHWAYS PLANNING FLOW CHART (RURAL SYSTEM ORIENTED)

3. Limited improvement budgets make highway transportation economics the critical constraint in designing a priority system. Maximizing the return for invested capital is desirable and this is achieved by applying the following policies:

   a) No capital investment in highway construction should be made which yields return less than the rates of secure investments such as U. S. Savings Bonds, insured saving accounts, etc.

   b) For any project or group of projects the capital improvement program yielding the highest profit (return) should be preferred.

   c) Unless improvements amortize their cost and yield the minimum rate of return, the existing facility should be retained and preserved.

4. The use of a cost-effectiveness approach to the systematic priority analysis of highway programming involves a detailed factual survey of the highway system. Estimation of construction and maintenance costs is a basic requirement for such technique and an economic measure of the highway service is also essential. Accident costs, congestion and delay costs, and motor vehicle operating costs are the essential aggregates for quantifying the highway transportation service and the means of measuring improvement benefits.

5. For a successful application of an economic priority model, objective measurement should substitute for subjective judgement that has been used extensively in rating procedures.

6. The systematic economic priority analysis of highway improvements is not sensitive to the possibility of adverse social consequences that may be by-products of some improvements. Detailed evaluation of such possibilities must be reviewed at later stages of the programming process.
7. The highway administrator has to consider factors such as: (a) adequacy of his staff, (b) program balance in allocating construction funds to districts, geographic areas and class of highways, (c) continuity of route development, (d) commitments and coordination with other planning activities, and (e) lead time between the different phases of highway construction. For such reasons the development of a priority system is by no means the end of the programming process.

The Benefit-Cost Ratio Analysis Approach

The extensive amount of planning activities preceding the priority system is shown in Figure 1. Highway systems physical inventory, traffic and accident surveys, fiscal study and needs study provide essential input to the priority programming process. The information assembled by these studies is a sufficient descriptor of the highway system for programming purposes. Implementing an economic priority model requires transforming the physical data into economic measures. The success of the priority model is conditional to the quality of the quantification process. Chapter IV will be addressed to that process exclusively.

The benefit-cost ratio analysis provides a conceptually sound basis for combining the economic measures of a highway section with an

evaluation of the efficiency of improvement alternatives. The theoretical foundations of the benefit-cost ratio method have been thoroughly reviewed in the literature (54). Basically, it amounts to evaluating the benefits and costs of each alternative and then comparing in the form of a ratio the benefits to the costs on an incremental basis. The alternatives are considered in the order of increasing costs with existing conditions forming the basis of initial evaluation (when that is possible). The plan providing the highest initial benefit-cost ratio is proposed in this work as the plan which should be chosen. For the priority analysis the following benefit-cost model is proposed:

$$MBC_j = \text{Max}\ (BC_{1j},\ BC_{2j},\ \ldots\ BC_{ij},\ \ldots\ BC_{nj})$$

and

$$BC_{ij} = \frac{R_{oj} - R_{ij}}{H_{ij} - H_{oj}}$$

$$R_{ij} = V_{ij} + Y_{ij} + X_{ij}$$

$$H_{ij} = C_{ij} + M_{ij} + C_{ij}$$

where:

MBC_j = maximum benefit-cost ratio of all improvement alternatives of highway section j,

BC_{ij} = benefit-cost ratio of improvement alternative i for highway section j,

R_{ij} = average annual roaduser cost of improvement alternative i for highway section j.

H_{ij} = average annual highway cost of improvement alternative i for highway section j,

V_{ij} = vehicular operating cost on highway section j with improvement alternative i,

Y_{ij} = time cost on highway section j with improvement alternative i,

X_{ij} = estimate of accident cost of highway section j with improvement alternative plan i,

C_{ij} = average annual capital cost of improvement plan i of highway section j; it includes ammortization of the principal plus the interest,

M_{ij} = the average annual maintenance cost of highway section j with improvement plan i,

O_{ij} = the average annual operation cost of highway section j with improvement plan i,

i = 0, 1, 2, ..., n and i=0 designates existing conditions,

j = 1, 2, ..., m identifies the highway section with m the total number of sections in the system considered.

Some routine maintenance operations performed by state agencies, such as pavement marking, are assumed to cost the same for all improvement alternatives. The costs of other items, such as traffic law enforcement, are also assumed to remain constant for all improvement alternatives.

By arranging projects in the order of decreasing maximum benefit-cost ratio (MBC_j) and scheduling them in that order, the maximum return for invested capital is achieved.

$$MBC_1 \geq MBC_2 \geq \cdots\cdot \geq MBC_L \geq \cdots\cdot \geq MBC_K$$

where:

MBC_1 = the highest maximum benefit-cost ratio reported in the MBC set of K highway sections,

MBC_2 = the second highest benefit-cost ratio reported in the MBC set of K highway sections, and so on.

Figure 2 is a graphical representation of the procedure. The abscissa is the cumulative annual capital costs while the ordinate is the cumulative annual benefits. For project L as an example, ΔC_L is the additional costs over existing conditions for the best improvement alternative and ΔB_L is the additional benefits over existing conditions for the best improvement alternative.

$$\frac{\Delta B_L}{\Delta C_L} = MBC_L$$

The prescribed sequence results in a convex surface. The benefits are maximized for any level of capital outlay by such sequencing. For example, for total annual costs of T_K the corresponding total benefits B_K is the maximum possible. The proof of such a property, given by Smith (50) in 1956 but surely well known before, applies to a variety of convex schedules.

Due to the fact that improvement capital is limited, possible improvement alternatives of a highway section were only compared to existing conditions. The alternative with the highest resulting

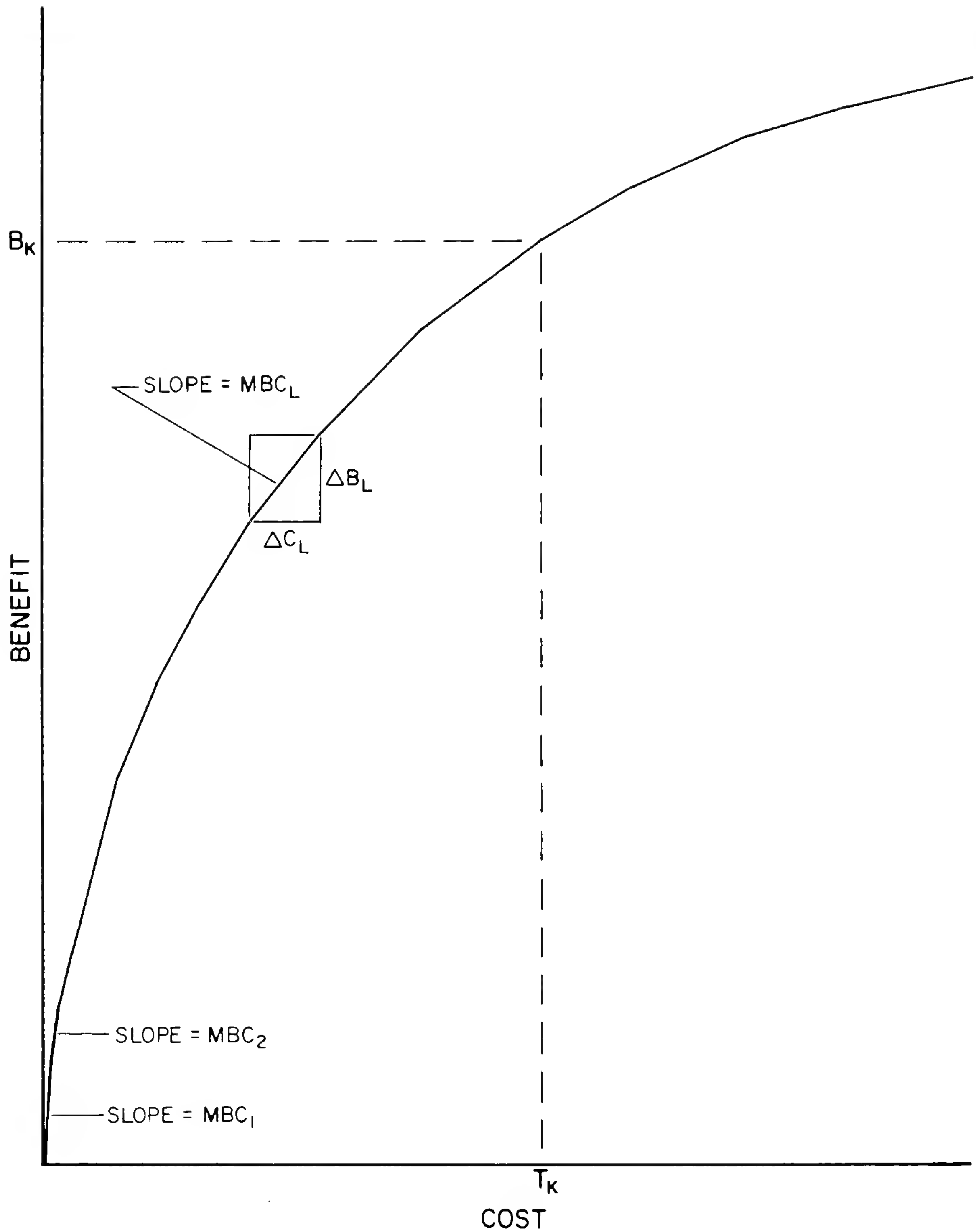

FIGURE 2. GRAPH OF A PRIORITY SEQUENCE BY ORDER OF DECREASING BENEFIT-COST RATIO

benefit-cost ratio was chosen and quoted as the priority rank of that section. No attempt was made to examine the benefit-cost ratio of additional costs of alternatives. Such an examination should undoubtedly be considered at the preliminary engineering phase of the programming process.

The benefit-cost analysis is restricted by two major perplexities. Difficulties arise when certain consequences cannot be objectively metricized and in this model measured by dollar value. The second source of problems is the comparison of unlike alternatives where simple ratios or differences between costs or benefits do not provide a meaningful basis. Fortunately such difficulties that might reduce the usefulness of the technique do not arise at the priority level of highway planning. Alternative plans considered are of the same nature, and non-economic consequences, though they may exist, are normally not possible of identification in a state-wide priority analysis. The advisory role of any priority system is emphasized here; later evaluation of such consequences is possible when detailed information is assembled at advanced phases of the planning process such as preliminary engineering or right of way acquisition.

Application Example

The benefit-cost ratio economic approach to establish programming priorities was applied in this research but was limited to Indiana rural state two-lane highways. The term state highways includes the Federal (U. S.) and State (S. R.) systems. Although the concept is more general and could be extended beyond this application, several reasons were instrumental in limiting this work to the subsystems

defined above. The most important of these were:

1. Rating urban arterials by a systematic method is nearly impossible, as pointed out in Chapter II. For rural highways, standards are well established, deviations from these standards by existing highway sections are easily measured, improvement alternatives are then formulated and the whole process is readily adaptable to systematic evaluation by the digital computer. The problems of any urban arterial are unique to that location. Congestion at the intersections is the major deficiency in many cases; but the limited available right of way, the various intersection layouts and the different traffic movements require detailed engineering survey for every improvement plan. Such an approach is time and money consuming, just simply unfeasible.
2. Very few urban arterials will be improved to, or replaced by, expressway standards. Measuring the deficiency of existing arterials by comparing them to expressway performance (as some have suggested) is not realistic. Estimation of benefits of proposed construction of urban arterials improvements remains to be solved.
3. The highway sufficiency inventory data, essential information for any programming activity, was available for the state highway system only. To consider in urban areas the urban extensions of state highways alone is a short sighted approach. The improvement of the urban arterials that are under the jurisdiction of the state system should be coordinated with the comprehensive planning effort of the community and not considered separately.

4. The analysis of the needs of county roads and the establishment of a priority program for those needs is another opportunity to apply the benefit-cost ratio economic approach. Such application should be performed separately by county road systems to insure a more accurate evaluation of the cost parameters and a stronger feedback into the results. No attempt was made for such an application in this research investigation due to the limited time and budget.
5. Only existing two-lane rural state highways were considered. The Interstate and the four-lane systems were excluded. By building the Interstate system to high geometric and structural standards, the thought of an obsolete Interstate system within the present planning horizon is remote. The majority of the four-lane state and federal rural highways in Indiana were recently built (many are still under construction), and they operate at a high level of service. The few isolated sections that need improvements have unique deficiencies that are not readily adaptable to systematic evaluation.

The establishment of a priority system is the first step in the programming process. The needs of the various highway sections are examined then ranked according to a prescribed criterion. The economic model proposed in this investigation ranks construction improvement projects by their benefit-cost ratios, a purely economic cost effectiveness approach. As such, the results of any priority procedure are advisory in nature, i.e. the first ten most worthy rated projects as determined by this approach are not necessarily the first ten

projects to be scheduled for construction by the state highway commission. There are other factors to consider in formulating the programming schedule. This is true for the proposed model and all other priority ratings as well.

A geographic balance in spending construction funds is sought by all highway departments. This insures that construction projects cover all the districts in the state. This is one of the most important factors that should be considered in the programming process. The coordination with other planned activities is a second influencing factor. Projects are advanced or withdrawn in a continuing effort to integrate related construction activities.

To provide motorists with a continuous consistent homogeneous highway system many projects receive advanced construction scheduling. For example, an isolated two lane section, the only remaining link between long stretches of a four lane divided highway, is a high priority project regardless of its benefit-cost rating. A fourth factor not usually ignored is political pressure. State commitments to other agencies pertaining to work and construction sequences is another administrative consideration. This is particularly important where agreements extend into the future and include routes to be constructed with other states.

The last important consideration to be mentioned is the availability of federal aid for highway work. This factor is not easily accessed at the early stages of the planning process. The burdens of financing the construction programs are eased when certain projects qualify for federal funds; such projects then receive preference in all realistic program schedules.

The results of applying the proposed economic model to the Indiana state rural two-lane highway network are presented in Chapter V. The top forty projects, those with the highest benefit-cost ratio measure, in each of the six highway districts in Indiana are listed. They should be useful in the highway programming process.

CHAPTER IV. QUANTIFICATION AND EVALUATION OF COST ELEMENTS AND DECISION PARAMETERS

General

The economic priority model presented in the preceding chapter employs the benefit-cost ratio analysis. The model is conceptually simple and easy to apply. The approach has been suggested and attempted by many. Its successful application, however, is conditional to the complete and accurate quantification of all cost elements involved in the economic decision process. The transportation cost elements and decision parameters necessary for a working model are classified as follows:

1. Roaduser costs,
    a. Estimates of operating costs of vehicles of respective highway sections before and after improvements,
    b. Estimates of accident costs of highway sections before and after improvements.
2. Capital costs of highway construction,
    a. Estimates of roadway construction costs (new alignment),
    b. Estimates of roadway reconstruction costs (limited improvement),
    c. Estimates of maintenance costs,
    d. Estimates of bridge construction costs.

3. Right of way costs and requirements,

   a. Decisions on rights of way requirements,

   b. Estimates of rights of way costs.

A major part of the research effort was devoted to building regression models, estimating values and computing statistics of the above mentioned items. Equal attention and detail was exercised at all phases to insure the same level of accuracy and precision. No quality is gained by building highly sophisticated models at one phase when a rough estimate is the best one can do at the next step. The sources of information and data used by the quantification effort were limited to:

1. Published results,
2. The records of the Indiana State Highway Commission,
3. Studies and experiments on small controlled samples of the Indiana highway network.

A systematic statewide data collection on the entire highway network was not seriously considered at any stage of the investigation. It is conceded that a better and more elaborate priority system could be developed that way. The additional quality, however, does not justify the expense in time and money for a statewide survey. The policy of this investigation was to avoid such recourse.

State highway physical inventory and accident records, the best available descriptors of the performance and quality of service of the highway network, were the source of statewide input data. The quantification and evaluation of cost elements and decision parameters were focused to rely on that input.

Road-User Costs

Motor Vehicle Operating Costs

Motor vehicle operating costs for use in highway economic studies vary over time and from place to place. The AASHO Red Book (1), the origin of many available sources, is in continuous need of updating. Soberman and Clark (51) designed a method that relies on a computer program which generates tables of operating costs applicable over a wide range of speed, gradient, highway standard, surface type and specified level of service. The calculations were carried out in terms of units of consumption, such as gallons of fuel, thus permitting continuously updating of actual costs that reflect local conditions and changing unit prices. The program, a copy of which was supplied by the authors, was slightly adjusted to meet the requirement of vehicular operation on Indiana rural state highways. The following supply of general data was used by the program to prepare the users' cost tables:

Vehicle type,

Surface type,

Roadway type,

Level of service,

Unit costs,

Range of speeds,

Range of grades.

Three types of vehicles were recognized (passenger car, single unit truck, combination truck); only one surface type was considered for state highways (paved surface); two types of roadways were of importance (two-lane and four-lane divided); levels of service from A to E were used in table preparation; the range of speed was limited

between 30 to 65 mph (**free** flowing speeds below 30 mph are not experienced on state highways of Indiana; speeds above 65 mph are beyond the speed limit and should not be used in an economic analysis); the range of grade was 0 to 6 percent; finally, the unit prices were selected and are given in Table 1.

The unit prices given in Table 1 are average market prices in Indiana in 1970 for the items listed. Winfrey (57) presents a well documented argument for excluding taxes from unit prices. A cost value for the time spent by trucks on the highway is an accepted proposition (57). A cost value for the time spent by a passenger car on the highway, on the other hand, is a controversial issue. Many studies (6) show that drivers do place a dollar value on the time spent driving even though that time cannot be classified as employable time; some people, however, still argue against including such value in any economic analysis.

If time consumed while driving a passenger car is of no value, and assuming that a driver is rational in optimizing his state, then an operating speed of 40 mph would minimize his total operating costs. Free flowing speeds on two lane highways in Indiana average close to 65 mph. If monetary scales are the best measures of a driver's utility, only when time has a value of $2.50/hr. or more would the total operating costs of a passenger car be minimal above 60 mph. Tables A1 to A6 in Appendix A, generated by the program, present the operating costs of the three types of vehicles on two-lane and four-lane divided highways. The units of operating costs in these tables are dollars per thousand vehicle miles.

TABLE I. AVERAGE UNIT PRICES USED IN CALCULATING ROAD-USER COST

UNIT COST \ VEHICLE TYPE	PASSENGER CAR	SINGLE UNIT TRUCK	COMBINATION TRUCK
FUEL* (¢/GALLON)	23	22	18
OIL (¢/GALLON)	70	50	25
TIRES ($/TIRE)	25	100	250
VEHICLE DEPRECIABLE VALUE (S)	2800	3500	19,000
LABOR COST ($/HR)	5.00	5.00	5.00
TIME COST ($/HR)	3.00	4.75	6.50

* VALUES DO NOT INCLUDE TAXES

The use of Tables A1 to A6 in computing operating costs on existing or improved highway sections is conditional to the availability of the following information:

1. Roadway grade,
2. Traffic volumes and classification of traffic by the three types of vehicles,
3. Operating speeds on the section,
4. The levels of service of traffic operation.

The highway terrain was identified as either flat, rolling or hilly and coded accordingly in the sufficiency inventory. A flat terrain was assumed to be of zero grade while rolling and hilly terrains were assigned two and four percent gradients respectively.

The highway inventory reports average daily traffic, peak hour factor and rate of traffic growth in addition to the section length for all sections of the highway network. The design hourly volume and the design annual vehicle-miles of travel for the average year in the design period (the design period being 25 years) were then evaluated. The percent of commercial vehicles in the traffic stream is also listed in the inventory. Using the truck classification results of the most recent loadometer studies, the traffic volumes and subsequently the annual vehicle miles of travel of each of the three types of vehicles under consideration were estimated.

The operating speeds of passenger cars on two-lane highways were estimated using a regression model developed in this research and reported in detail elsewhere (29). A summary of this model is presented in the next section. The operating speeds of passenger cars

on proposed four-lane highways were estimated using the HCM, *Highway Capacity Manual* (31). Proposed sections are to be built to high geometric standards and were considered as ideal sections. The operating speed is mainly a function of the design hourly volume.

$$VEL4 = 67.9 - (25/3000)\ DHV$$

where

VEL4 = the operating speed on four lane proposed improvements, (not to exceed 65 mph),

DHV = design hourly volume in both directions (67.9 was the average free flowing speed on four lane highways in 1969 in Indiana; 25/3000 means an increase in 3000 vph reduces the speed by 25 mph, according to the HCM).

The operating speeds of single unit and combination trucks on two lane highways were those of passenger cars minus 4.2 and 8.7 mph respectively. On four-lane highways operating speeds were those of passenger cars minus 3.7 and 9.7 mph respectively. These adjustment factors were obtained from the 1969 Indiana speed study (28).

The levels of service for existing highway sections and proposed two lane or four lane highway facilities were determined using criteria outlined in the *Highway Capacity Manual*. The level of service is a function of the operating speeds, the hourly volumes and the type of terrain; three parameters already defined and evaluated. Once all the operations are defined, the task of computing the values of parameters for level of service, traffic volumes, operating speeds, etc. is a decision free process. Applying these values to determine the motor vehicle operating costs for any highway section is as simple. All

these operations were programmed to be performed by the digital computer on a systematic basis. These subroutines are included in Appendix B.

Predicting Travel Time on Two-Lane Highways

The task of the study summarized in this section was to determine the effects of factors such as traffic, geometric conditions and pavement structural conditions on travel time (operating speed) on two-lane rural highways. A stratified sample of 120 highway sections on Indiana rural state highways was selected and travel time was measured by the average car method. Several runs in both directions were made to obtain representative average running times.

Parameters such as traffic volumes, width of pavement, etc. were measured; while other variables describing roadway characteristics, such as length of no passing zone, terrain, etc. were obtained from the records of the sufficiency inventory of rural state highways. The operating speed was the dependent variable in the stepwise linear regression used to interpret travel time as a function of physical and traffic roadway conditions. A model containing only six independent variables predicted operating speeds with a high degree of accuracy, $R^2 = .903$, and standard error of estimate of 1.876 mph. The values for the model (regression coefficients, standard errors, etc.) are given in Table 2. The following are the dependent and independent variables used in the model:

1. Operating Speed. This is the dependent variable in the regression analysis. Identified as SPEED.

TABLE 2. SUMMARY OF TRAVEL TIME REGRESSION MODEL

R^2 Coefficient of Determination . . . . : 0.903

Standard Error of Estimate . . . . . . : 1.876 mph
(the square root of the residual mean square)

INDEPENDENT VARIABLE	REGRESSION COEFFICIENT	STANDARD ERROR	F* TO REMOVE	VARIABLE RANGE AND DESCRIPTION
CONSTANT	38.43	—	—	
X_1	-.0113	.00115	95.36	6-1000, VEH/HR
X_2	-7.0143	.56599	153.59	0-2.5, TRC/LN
X_3	1.0452	.10193	105.14	18-30, WIDTH
X_4	-.3076	.04714	42.58	0-17, S.S.D.
X_5	-.1049	.01342	61.05	0-48, ALIGNE
X_6	-.1073	.01709	39.41	0-22, NO PASS

* Test of Significance of Regression Coefficient with Model Containing All Selected Independent Variables

2. Traffic Volume. This is the volume of traffic, expressed as vehicles per hour. Identified as VEH/HR.

3. Traffic Interruptions per Mile. A traffic interruption is defined as either a stop sign, a traffic signal, or any other traffic event for which at least one-half of the traffic is required to stop or severely slow down. Such an interruption could be located at the beginning, end or anywhere on the section. The total number of these traffic interruptions is divided by the length of the section to yield this variable. Identified as TRC/LN.

4. Width of Pavement. The actual width of the usable pavement. Identified as WIDTH.

5. Stopping Sight Distance Restrictions. The total number of locations where sight distance is below the minimum standard for the highway class is reported for each section in the Indiana Inventory records. If no restrictions are present, a value of zero is recorded. The abbreviation for this variable is S.S.D.

6. Alignment Factor. For each horizontal curve where the degree of curvature exceeds the design standard, the excessive number of degrees (difference between actual and maximum allowable) are totaled for substandard curves on the section. This is reported in the inventory and is identified by ALIGNE.

7. Restricted Passing Sight Distance. The length of restricted passing sight distance, measured by logging in tenths of miles the amount of the section with a yellow barrier line is also reported in the inventory. This is another independent variable used in the regression and designated as NOPASS.

Motor Vehicle Accident Costs

An objective of this research was to incorporate the cost of motor vehicle accidents in the priority system. This made the need for more accurate accident cost data a recognizable certainty. For this purpose, a comprehensive accident study on Indiana rural state highways was conducted as an adjunct part of this investigation. The records of all accidents reported on Indiana rural state highways for the years 1967 and 1968, obtained on computer magnetic tapes from the Division of Traffic of the Indiana State Highway Commission, were used by the study. The detailed description and results of this study are reported elsewhere (30). The following estimates for the total direct costs of reported rural state highway accidents were determined by the study:

Accident by Severity Class	Total Direct Cost per Accident (1970$)
Fatal	18,605
Non Fatal	4,280
Property Damage Only	606
All	2,433

The cost of unreported accidents was estimated by that study to be 15 percent of the total accident costs on rural state highways.

The location of an accident was one of the major information groups contained in the accident records. The 1967 and 1968 accident records used the 1966 sufficiency inventory coding system for location identification. Location items, such as, county number, highway number, control section code, and subsection number made it possible to accumulate by the digital computer all accidents of the same location (same highway, county, and inventory subsection) using sort and merge

techniques. The accident information thus amassed and aggregated augmented the 1966 sufficiency inventory data. That is, an augmented inventory record contained additional information, the number and severity of all reported accidents that occurred in 1967 and 1968 on a highway subsection. Unfortunately many of the subsections of the 1970 sufficiency inventory carried different codes than the corresponding subsections in the 1966 sufficiency inventory. The transfer of the accident information from the 1966 records to the 1970 records, which were used by this research, had to be done manually.

To determine accident costs on existing highway sections two methods were possible:

1. Multiply the total number of accidents in each of the three severity classes by the corresponding total direct cost per accident, respectively, and add the three products to obtain the actual direct cost of all accidents for each inventory section.
2. Multiply the total number of accidents, regardless of severity, by the average direct cost for all accidents to obtain an estimate of the actual average direct cost of accidents for each inventory section.

Method two was selected for the following reason. Accidents can be envisioned as the result of a random process of low probability. The total number of accidents on highway sections with low accident rates seldom exceeded three for the two year period 1967-68. Fatal accidents occurred at lower frequencies. If any of the accidents happened to be a fatal one, a possible phenomenon with very low probability, the total accident cost on such a highway section would be exceedingly high

using method one, and a distorted picture for the section would result. On high volume, high accident rate highways distortion from an above average number of fatalities is also smoothed while the costs resulting from the high accident rate are indicated.

The problem of estimating accident costs on highway sections after improvement is different from that on existing sections before improvements where two years of accident experience was available. The safety record of improved highway sections was examined for the following three classes of improvements:

1. Four-lane divided highway sections built to high design standards,
2. Two-lane highway sections built to high design standards,
3. Two-lane highway sections rebuilt to acceptable standards; this includes highway sections where the pavement was widened to 24 feet with some improvements to the alignment.

Several statistics and techniques, including regression analysis were examined as possible means of estimating accident costs after improvement. The input data were from existing inventory sections that belonged in the three classes of highways listed above. Only one statistic, the average cost of accidents per vehicle-mile of travel, showed reasonable consistency and moderate coefficients of variation for all three classes. The accident costs per vehicle-mile of travel selected to be used for estimating the accident costs on improved and/or new highways were as follows:

Highway Type	Accident Costs Per Vehicle-Mile of Travel
Four-lane divided highways, high design standards	¢ 0.445
Two-lane highways, high design standards	¢ 0.510
Two-lane highways improved to acceptable standards	¢ 0.570

Highway Construction, Capital Cost Models

Four different phases of highway construction, identified as separate activities, were roadway construction, roadway reconstruction, roadway maintenance and bridge construction. Each of these activities is an expensive operation usually performed by contractors on behalf of state highway agencies. Ordinarily, a contract would not involve more than one activity. The description of the site, type of work involved and the money expenditure is well documented in the plans, contract documents and financial records of the State Highway Commission. These were made available for this investigation.

A literature search did not produce any models, figures or tools to aid the capital costs evaluation of improvement alternatives used in the priority system. Cost values used and reported by similar studies were either out of date and scope, or required a detailed description of the alignment and other input data, a task unattainable at this level of the planning process. As a result, a detailed study of capital expenditures on Indiana rural state highways was conducted. The following is a summary of the procedure and results.

Procedure

The listings and summaries of all contracts awarded by the Indiana State Highway Commission from the year 1960 to 1969, inclusive, were examined. The location of each contract was identified and accordingly only those located on exclusively rural state highways (excluding the Interstate system) were considered. At the same time, contracts that were still pending, financially disputed, in progress or not completed were eliminated. The remaining jobs (824 contracts) were classified according to the general type of work involved.

1. Roadway construction - This includes all construction of two or four lane highways on new right of way and the construction of two or four lane highways with a new alignment using partially or completely existing right of way.
2. Roadway reconstruction - This is a limited improvement type of work. It includes pavement widening, shoulder construction, horizontal and/or vertical alignment improvement through pavement base lifting, or complete rebuilding of a small percentage of the roadway's length.
3. Roadway Maintenance - These activities were mainly pavement resurfacing, patching, sealing and wedging.
4. Bridge Construction - A bridge project was defined as any structure with a span length of more than twenty feet.

Separate analysis was performed on each contract set of the four classified types of highway construction. These sets were mutually exclusive; that is, a contract belonged to only one type of construction.

Each contract was considered as a single piece of data or an observation in that set. Multiple linear regression was chosen from several possible methods of analysis. Four regression models were sought to describe and explain quantitatively highway construction costs over the past ten years and predict the cost of similar future improvements.

The desirable statistical qualities of regression analysis were not the only justification for its choice as the method of analysis and form of modeling. The purpose of the evaluation and the structure of the information available dictated the choice. At the early stages of programming when statewide priorities are being considered, items that determine the exact construction cost, such as quantities of earthwork, concrete, guard rail, etc. are not available. Furthermore, the location of improvements and the description of alignments can not be determined. This necessitated describing improvements and their cost by general terms that could be procured from the highway inventory.

Construction summaries, plans, maps, contract documents, and payment schedules were examined when necessary to obtain information that described the work performed and the total amount of money spent for each contract used in the analysis. The information could be generally classified into four groups:

1. Total contract cost,
2. Year of completion,
3. Length of the section built, resurfaced, etc.

4. Assessment and description of the work; examples: the type of terrain for roadway construction, the type of paving surface for roadway maintenance, and length of bridge span for bridge construction.

The regression analysis dependent variable was expressed and computed as cost per mile of highway for the first three models, and per bridge for the bridge construction model.

The date (year) of completion was an important parameter in selecting the rate of inflation. The consumer price index measures the variation in prices of many vital economic commodities. It fails, however, to quote any values for aggregated highway construction. Though labor and machinery prices have been on a steady rise in the last decade, better equipment and advanced construction practices have compensated for much of that rise.

To account for all factors involved, an annual constant rate of inflation that best fit the data was sought for each model. The construction cost (dependent variable) of each contract (observation) was discounted to present worth dollars (1970) using a constant annual rate of inflation. Eleven rates from zero to five percent at half percent increments were tested as possible average annual rates of inflation for each regression model. The rate that produced the best fit, least coefficient of variation, for the final regression model was selected for that model. A value of one percent was found to be the average rate of inflation for roadway construction and reconstruction, models I and II, while three percent was the choice for roadway maintenance and bridge construction, models III and IV. The dependent

variable and the coefficient of regression were all expressed in terms of 1970 dollars for all four models.

The independent variables in the regression were defined and selected to describe the activities performed in the contracts. Dummy variables were used extensively in all four models. A dummy variable would take a value of one when a certain activity was performed in a contract but would remain zero otherwise. In maintenance contracts, for example, if the existing pavement had to be patched before surfacing the dummy variable PATCH in that model would be assigned the value of one. The variable PATCH would be zero otherwise.

The stepwise linear regression analysis was performed by program BMD-2R (13). All four models reported an R^2, coefficient of determination, of 0.791 or better. The coefficient of variation, another statistic used to measure the quality of regression, of all four models was satisfactorily low. The residuals, difference between observed values and predicted values, were examined for possible nonconformity and eccentric misinterpretations. The results were negative. The use of linear regression as the model form seemed to be a successful choice.

The regression analysis model in equation form is:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n + \epsilon$$

where Y is the dependent variable, the construction cost, X_i's are the independent variables, β_i's are the regression coefficients estimated by the least square method by program BMD-2R, and ϵ is the random error term. In the models' final form only the significant independent variables were included. Numerous other independent variables were tested in the analyses. Such variables did not contribute to the

estimating power of the models (non significant) and were not included in the models.

Model I - Roadway Construction

The dependent variable in this regression analysis is the construction cost per mile of roadway. Ten significant independent variables are included; the first four describe two lane highway construction while the remaining six are associated with four lane divided highways. The nomenclature and description of the variables are:

1. NROW2L. A dummy variable that assumes the value of one for the construction of two lane highways on new right of way and is zero otherwise.
2. CROW2L. A dummy variable that takes the value of one for the construction of two lane highways with new alignment on partially or completely old right of way and is zero otherwise.
3. TERR2L. This variable measures the effect of the terrain on the construction cost of two lane highways. It assumes the values of zero, one and two for flat, rolling and hilly terrains, respectively.
4. STRCT2. A dummy variable that takes the value of one for extensive culvert and retaining wall work on two lane highways and is zero otherwise.
5. CROW4L. A dummy variable that assumes the value of one for the construction of four lane highways with new alignments on partially or completely old right of way and is zero otherwise.

6. NRCW4L. A dummy variable that assumes the value of one for the construction of four lane highways on new right of way and is zero otherwise.

7. ADD2LN. A dummy variable that assumes the value of one when a two lane highway is converted to a four lane divided facility by constructing two additional lanes; it is zero otherwise.

8. MAJIMP. This dummy variable identifies, by assuming the value of one, major improvements performed on an existing two lane highway while two additional lanes are being constructed. It remains zero otherwise.

9. TERR4L. This is the four lane counterpart of variable TERR2L.

10. INTCH4. The average roadway and earthwork cost of each interchange is included in the total cost of construction by this variable. The number of interchanges in the project is the value of this variable.

The model results are given in Table 3.

Model II - Roadway Reconstruction

The dependent variable in this regression analysis is the cost of reconstruction per mile of roadway. Five independent variables are included in this model that estimates the cost of rebuilding deficient existing two lane highway sections to acceptable standards. The independent variables are:

1. MINCON. A dummy variable that takes the value of one when extensive minor pavement repair work is required and remains zero otherwise.

TABLE 3. SUMMARY OF MODEL 1-ROADWAY CONSTRUCTION

Dependent Variable Name . . . . : Construction Cost Per Mile (1970 $)

Mean . . . . : 271,300 (1970 $)

Average Annual Inflation Rate . . . . . . : 1.0%

Standard Error of Estimate, Se . . . . . : 33,600

Coefficient of Variation, C.V. . . . . : 12.0%

Coefficient of Multiple Determination, R^2 . . : 0.951

Number of Observations . . . . : 84

INDEPENDENT VARIABLE	REGRESSION COEFFICIENT (1000)	STANDARD ERROR (1000)	F TO REMOVE	VARIABLE RANGE AND DESCRIPTION
CONSTANT	0.0	—	—	not included in this model
X_1	185.8	7.78	569.9	0 or 1, NROW2L, dummy v.
X_2	109.7	9.64	129.5	0 or 1, OROW2L, " "
X_3	83.7	12.0	14.8	0-2, TERR2L,
X_4	53.6	14.8	13.2	0 or 1, STRCT2, dummy v.
X_5	217.0	17.8	147.4	0 or 1, OROW4L, dummy v.
X_6	300.4	7.48	1611.9	0 or 1, NROW4L, " "
X_7	178.8	12.7	197.7	0 or 1, ADD2LN, " "
X_8	52.5	18.7	7.87	0 or 1, MAJIMP, " "
X_9	153.2	9.34	269.1	0-2, TERR4L,
X_{10}	155.5	13.6	130.4	0-2, INTCH4.

2. MAJCON. The percentage of the project's length, expressed as multiples of ten percent, where the roadway is completely rebuilt is the value of this variable. Twenty percent was the maximum fraction of a project length which was rebuilt by a reconstruction contract during 1960-69; this maximum value corresponds to a value of two for this variable.
3. THICKM. This is the thickness of an asphalt surface applied to the existing pavement. The nominal width of this surface is 24 feet. A pavement less than 24 feet wide is usually widened before resurfacing as part of the reconstruction contract.
4. WIDE. A reconstruction improvement project is usually committed to a standard 24 foot wide pavement surface as a final product. The necessary widening of an existing pavement surface to achieve that width, is the value of this independent variable.
5. SHLDR. The width of each improved shoulder, measured in feet; multiplied by the depth of the compacted aggregates used, measured in inches, is the last significant roadway reconstruction independent variable.

Table 4 gives a summary of the model results.

Model III - Roadway Maintenance

Pavement resurfacing is the only activity described by this model Other routine roadway maintenance activities are excluded from the analysis; the argument for this deletion was detailed in Chapter III. The maintenance or resurfacing cost per mile is the dependent variable

TABLE 4. SUMMARY OF MODEL II-ROADWAY RECONSTRUCTION

Dependent Variable Name............: Reconstruction Cost Per Mile (1970 $)

Mean...........: 32,100 (1970 $)

Average Annual Inflation Rate.......: 1.0%

Standard Error of Estimate, Se.....: 4,290

Coefficient of Variation, C.V..........: 13.3%

Coefficient of Multiple Determination, R^2: 0.906

Number of Observations..............: 236

INDEPENDENT VARIABLE	REGRESSION COEFFICIENT (1000)	STANDARD ERROR (1000)	F TO REMOVE	VARIABLE RANGE AND DESCRIPTION
CONSTANT	2.82	—	—	
X_1	6.02	0.641	88.3	0 or 1, MINCON, dummy v.
X_2	15.13	0.564	720.2	0,1 or 2, MAJCON, " "
X_3	4.11	0.345	142.1	0-6.5, THICKN.
X_4	2.27	0.153	220.2	0-9, WIDE.
X_5	0.36	0.044	67.5	0-50, SHLDR.

in this regression. Five independent variables are included.

1. HASPH. The thickness of the high type asphalt surface applied is the value of this variable. High type surfaces, such as Hot Asphalt Concrete (HAC) and Hot Asphalt Emulsion (HAE), are used for high traffic volume highways.
2. MASPH. The thickness of the medium type asphalt surface to be applied is the value of this variable. Medium type surfaces, such as Mix Seals and Bituminous Coated Aggregates (BCBA), are used on low traffic volume highways.
3. WEDGE. A dummy variable that assumes the value of one when bituminous wedges are needed to insure a uniform surface before applying the surfacing coat. It is zero otherwise.
4. PATCH. This dummy variable has the value of one when significant patching of the existing surface is needed before applying the new asphalt coat. It is zero otherwise.
5. WIDTH. This is the width of the applied surface.

The values for the model obtained by the regression are given in Table 5.

Model IV - Bridge Construction

The dependent variable is the cost of construction of one bridge. The six independent variables selected by the stepwise regression analysis describe the bridge.

1. ROADLM. This is the length in miles of the bridge approaches to be built as part of the bridge contract. Such approaches are short in length and involve extensive amount of earthwork.

TABLE 5. SUMMARY OF MODEL III-ROADWAY MAINTENANCE

Dependent Variable Name . . . . : Maintenance Cost Per Mile (1970 $)

Mean . . . . : 10,900 (1970 $)

Average Annual Inflation Rate . . . . . . : 3.0%

Standard Error of Estimate, Se. . . . . . : 2,840

Coefficient of Variation, C.V. . . . . : 26.0 %

Coefficient of Multiple Determination, R^2 : 0.791

Number of Observations . . . . : 346

INDEPENDENT VARIABLE	REGRESSION COEFFICIENT (1000)	STANDARD ERROR (1000)	F TO REMOVE	VARIABLE RANGE AND DESCRIPTION
CONSTANT	-8.65	—	—	
X_1	5.90	0.327	326.5	1 to 4.3, HASPH,
X_2	5.02	0.395	127.4	1 to 3.0, MASPH,
X_3	3.61	0.415	75.7	0 or 1, WEDGE, dummy v.
X_4	5.56	0.448	154.3	0 or 1, PATCH, dummy v.
X_5	0.471	0.0483	94.9	18-24, WIDTH.

2. **SPANLN.** This is the total span length of the bridge measured in feet.

3. **LGSPAN.** This is the length of the longest span of the bridge measured in feet.

4. **PIER.** This is the depth of the piers measured in feet.

5. **C.W.** This is the clear width of the bridge deck, measured in feet.

6. **NOSPAN.** This is the total number of spans of the bridge.

Table 6 summarizes the results of the model.

Right of Way Requirements and Costs

At the priority programming stage of planning, the location of any proposed new highway is undefined. Thus the phrase "right of way (ROW) requirements" could be misleading. The decision is not quantitative on where and how much right of way is needed but rather qualitative as whether there is a need for new ROW or not. Three basic courses of action regarding ROW are available:

1. Utilize the existing ROW,
2. Utilize the existing ROW but acquire additional land,
3. Abandon the existing ROW and relocate the facility on new ROW.

These alternatives are functions of the envisioned improvement and the adequacy of existing ROW. Improvements are of two types, limited reconstruction that salvages existing alignment and ROW or new construction with a new alignment that might not use any of the existing present facility. It is not difficult to see the economic and social merits of utilizing existing ROW for reconstruction. For that reason, all existing highway sections had the limited roadway reconstruction

TABLE 6. SUMMARY OF MODEL IV-BRIDGE CONSTRUCTION

Dependent Variable Name...............: Cost of Bridge (1970 $)
Mean.............: 238,700 (1970 $)

Average Annual Inflation Rate........: 3.0%

Standard Error of Estimate, Se.......: 82,900

Coefficient of Variation, C.V. ....:34.8%

Coefficient of Multiple Determination, R^2..:0.926

Number of Observations...............:158

INDEPENDENT VARIABLE	REGRESSION COEFFICIENT (1000)	STANDARD ERROR (1000)	F TO REMOVE	VARIABLE RANGE AND DESCRIPTION
CONSTANT	202.9	—	—	
X_1	273.4	32.4	71.0	0-1.2, ROADLN,
X_2	.665	0.876	57.6	40-2290, SPANLN,
X_3	1.52	.301	25.2	22-720, LGSPAN,
X_4	1.76	.594	8.79	0-150, PIER,
X_5	3.63	.778	21.7	18-90, C.W.,
X_6	-8.98	7.12	1.57	0-20 NO.SPAN

alternative as a mandatory option, provided adequate ROW existed and regardless of traffic considerations.

Roadway reconstruction involves (a) widening of the existing pavement to 24 feet standard width if necessary, (b) providing compacted aggregate shoulders, (c) insuring safe embankment side slopes, (d) improving the horizontal alignment by superelevation of horizontal curves, etc. The practice in Indiana defines adequate existing ROW for such improvement schemes as 60, 80 and 100 feet wide for flat, rolling and hilly terrains, respectively. It is practically impossible to fit such improvements within narrower right of ways. A reconstructed section when feasible was always an improvement alternative considered in the benefit-cost ratio economic analysis.

In addition to comparing existing conditions with the limited improvement alternative, a completely new alignment is a second alternative. The number of lanes to be newly constructed is determined by traffic needs. The average daily traffic at the end of the design period (25 years) should determine whether to build a two lane or a four lane divided highway, seven thousand vehicles per day being the decision point. If the estimated daily traffic should exceed seven thousand within seven years after the planning date, all four lanes should be considered for construction. If the estimated daily traffic does not exceed seven thousand in the initial seven year period but does so before the end of the design period, only two lanes are considered for construction but ROW provisions are made for two additional lanes.

Figure 3 illustrates these volume relationships graphically in terms of present and design average daily traffic. Action I is limited

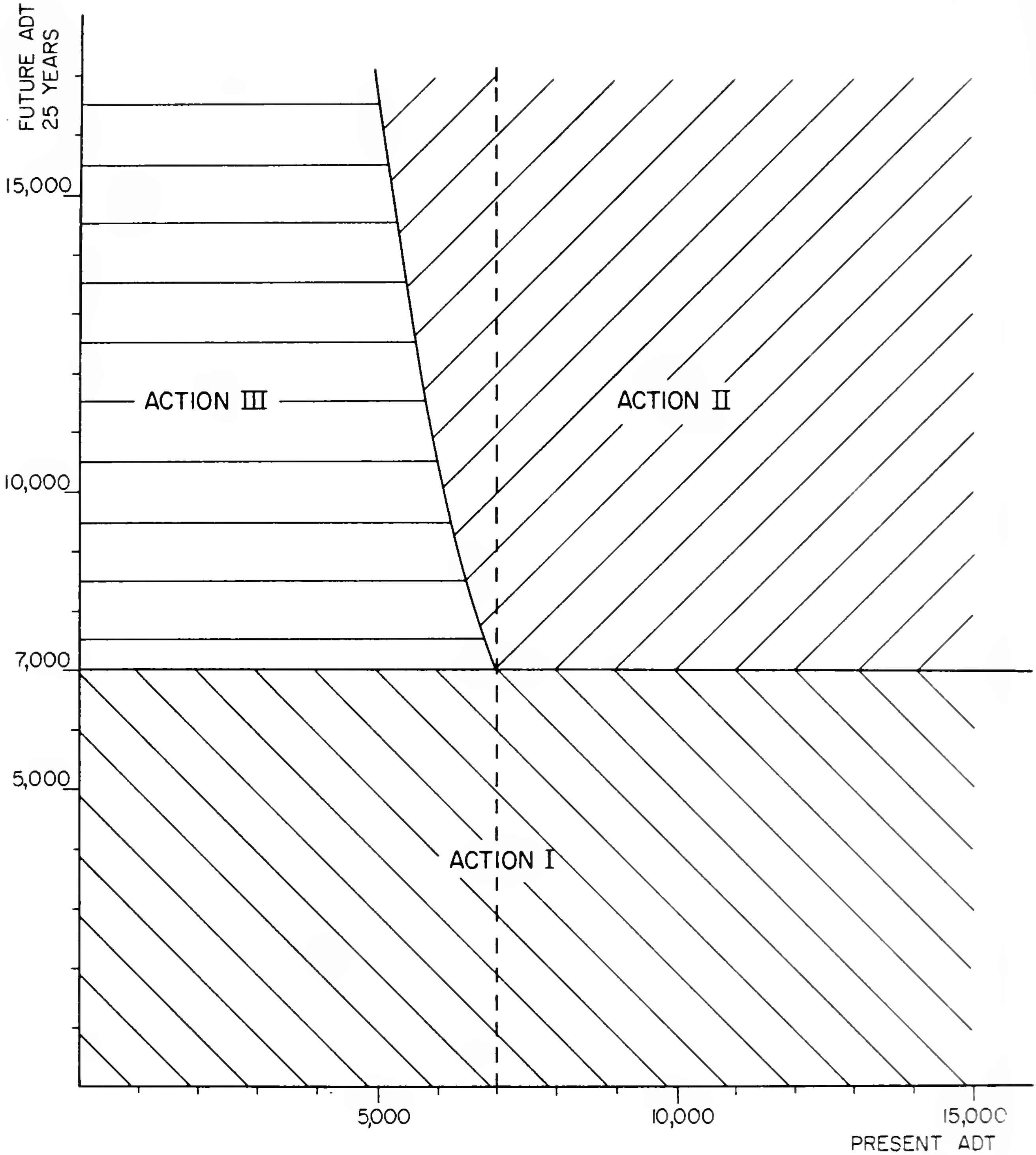

FIGURE 3. PRESENT-FUTURE ADT RELATIONSHIP DIAGRAM FOR ROW AND CONSTRUCTION DECISIONS

to a two lane highway only. Action II considers a four lane divided highway improvement now. Only two lanes are needed now when traffic parameters are in the action III region, but ROW is acquired for two additional lanes.

When feasible, new alignments (two or four lane facilities) should make use of existing ROW. The present sufficiency inventory records of rural highways limit the measure of feasibility to the width of the existing ROW. The current practice in Indiana is roughly mapped by the decision rule tabulated below.

		Width of Existing ROW		
Type of Improvement	ROW Requirement	Utilize Existing ROW Only	Acquire Additional ROW	Acquire Completely New ROW
New Alignment for Two Lane Highways		100 feet or more	80-100 ft.	less than 80 feet
New Alignment for Four Lane Highways		200 feet or more	150-200 ft.	less than 150 feet

While preliminary engineering estimates of construction costs are usually very close to final figures, it is not uncommon that preliminary estimates of ROW acquisition costs differ considerably from what is finally paid. Estimating ROW costs on a statewide basis is almost guess work. A study of ROW costs on a sample of 73 construction projects that did require ROW between 1965 and 1969 inclusive showed a large variation of average prices per mile of highway between similar jobs in the same year. No attempt was made to include any project before 1965 in the sample because of the sharp increase in land values since

1965. The following average unit prices for one mile of acquired right of way are based on the analysis of the sampled 73 projects.

Type of Improvement	ROW Cost $1000 per Mile
New ROW for Two-Lane Construction	52.3
Additional ROW for Two-Lane Construction	36.9
New ROW for Four-Lane Construction	145.7
Additional ROW for Four-Lane Construction	125.8

The above values are for 1970 and account for inflation in land values. They include a) relocation expenses, b) condemnation expenses, c) court fees, and d) preliminary engineering costs.

CHAPTER V. MODEL APPLICATION AND RESULTS

Programming the Economic Priority Model

The application of the economic priority model to the Indiana rural two-lane state highway network was performed using the digital computer. A Fortran IV program written for that purpose translated the concept developed in Chapter III into a sequential computational procedure. The flow diagram of the system logic is shown in Figure 4. The cost values and decision parameters evaluated in Chapter IV were included in the program. The description of the highway sections was provided by abridged inventory records, augmented with accident data. These served as the input to the program. In the programming process the following assumptions, shortcuts or rules were made:

1. The lengths of all improved sections were equal to that of the original sections they replaced. Such an assumption is frequently made in other planning activities.
2. The same traffic control arrangements were assumed for before and after conditions. For example, if a traffic signal existed at the end of a highway section, the signal was assumed to remain there after building possible improvement alternatives, such as resurfacing. Traffic interruptions due to traffic control devices do not change by this assumption and could thus be ignored in the economic analysis. This assumption is not unrealistic since reducing the economic

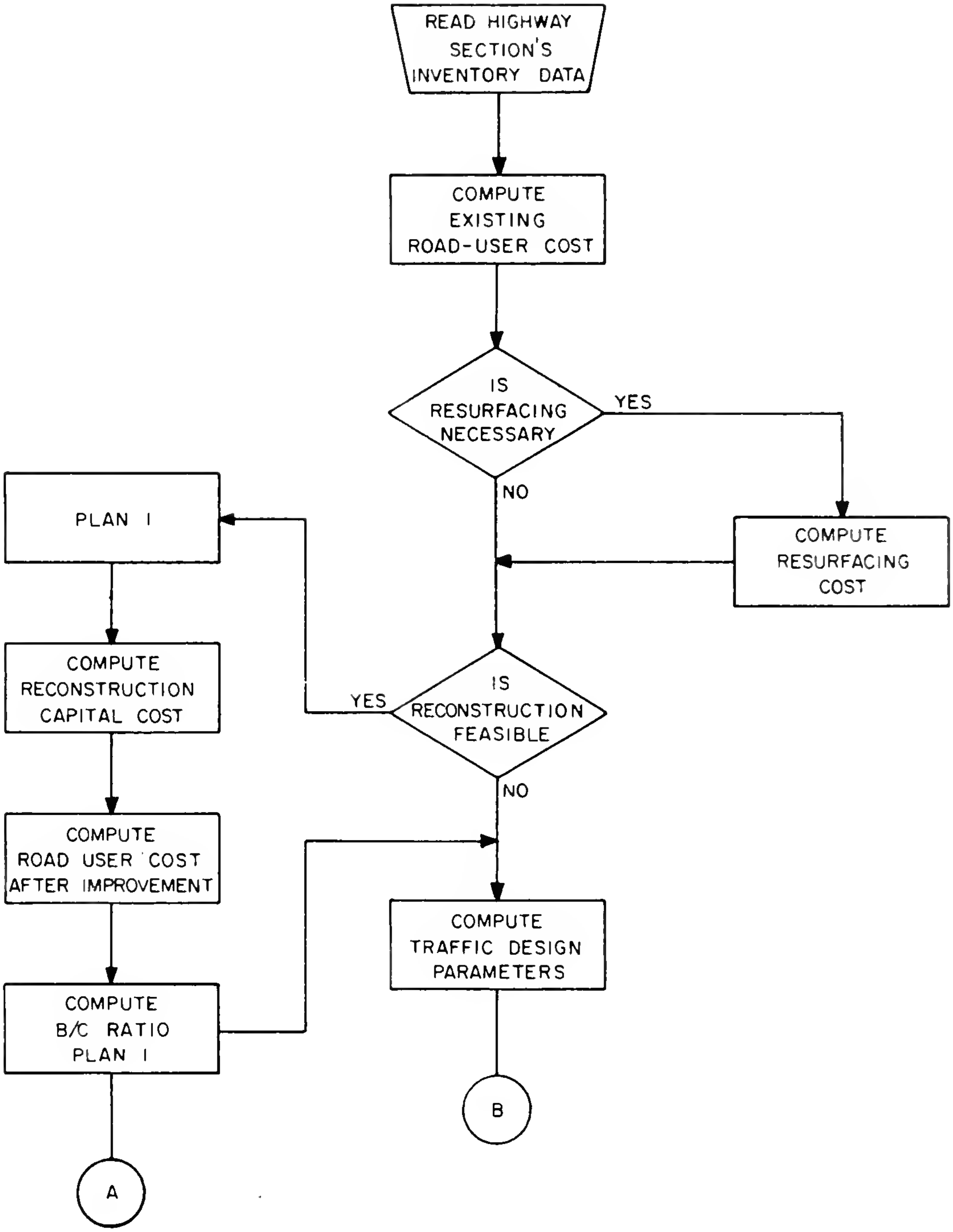

FIGURE 4. FLOW DIAGRAM FOR THE ECONOMIC PRIORITY MODEL

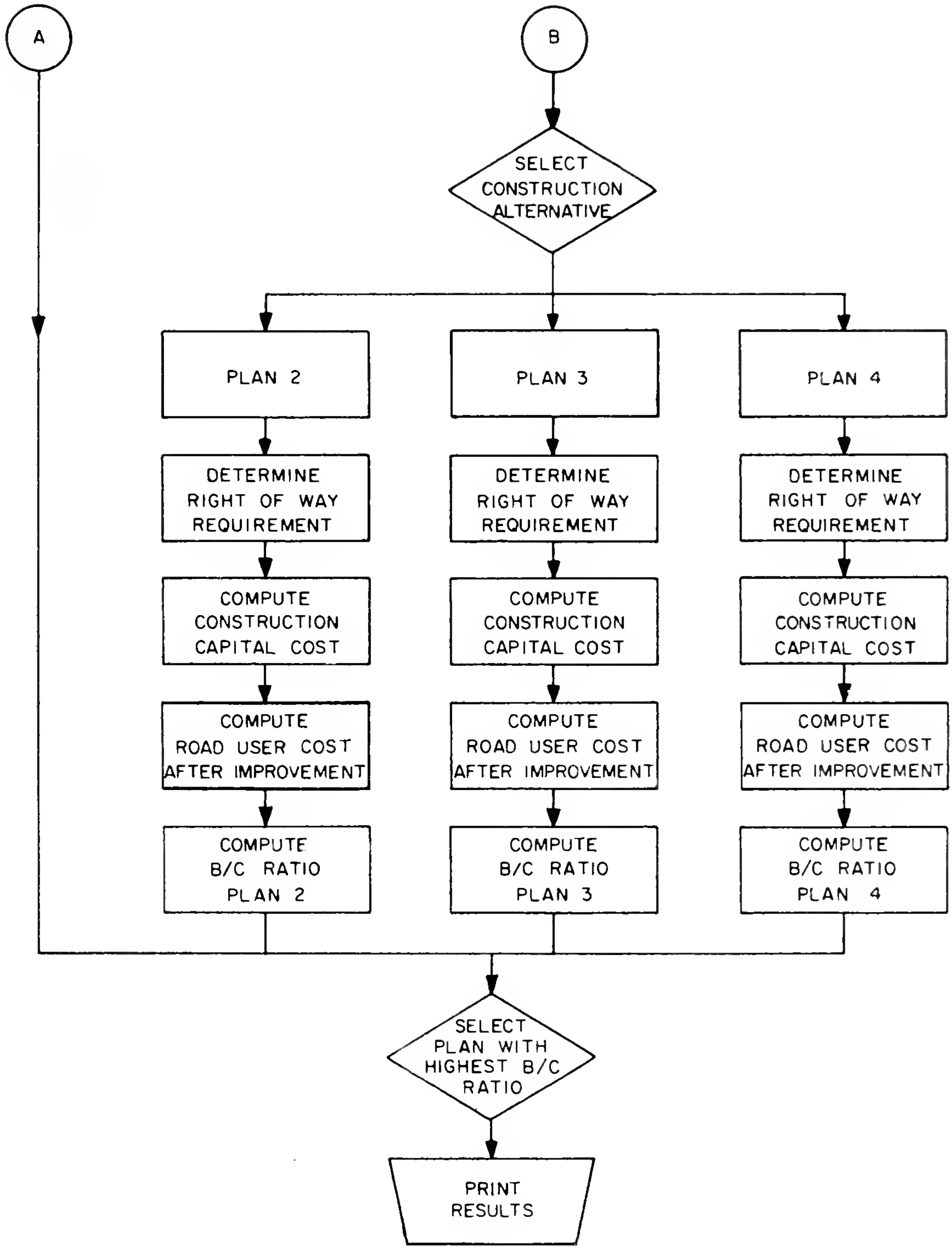

FIGURE 4. (CONTINUED)

losses of traffic interruptions by building interchanges is a rare phenomenon on rural two-lane highways.

3. Bridge costs were not applied to the Sections in which they were located. The cost of constructing bridges is a large investment. Including the cost of any bridge in the total cost of the highway section where such a bridge occurs makes that cost very high. This reduces the benefit cost ratio of the possible improvement of such sections and segregates them out of the top priority list. Following such a course of action would encourage building road sections free of bridges and a discontinuous, incoherent highway system would result. Moreover, an adequate bridge provides benefits to more of the route than just the short section in which it is located. The bridge costs for different improvement alternatives, therefore, were averaged for all sections and applied as a surcharge for each highway section on a mileage basis. For reconstruction programs, for example, forty thousand dollars per mile were added to the costs for all sections.
4. A six percent interest rate was chosen for the economic analysis. The choice was based on the rules outlined in Chapter III. To resolve arguments for different interest rate values, a partial sensitivity analysis conducted on the results, will be presented later.
5. The accidents that occurred in 1967 and 1968 were used to estimate accident costs for the sections where such accidents occurred. Two years experience, however, is not enough to

estimate with accuracy the average cost values of accidents, especially where these rates are low. In some cases the accident costs on existing sections as determined from the 1967-68 data were found to be less than the estimated costs on the improved sections. Where this took place the existing accident costs were assumed to be equal to the estimated accident costs of improved sections. This eliminated the paradox of improvements increasing accident costs on these sections.

A listing of the computer program is included in Appendix B.

Program Output

A sample page of the detailed and lengthy output is shown as Table 7. The highway inventory coding system used by the Indiana State Highway Commission was adopted by this investigation. The following six codes of information identify a highway section and its location:

1. The highway district code: Crawfordsville, Fort Wayne, Greenfield, LaPorte, Seymour and Vincennes districts were coded 1 to 6 respectively,
2. The highway number: the first digit is the highway system code (2 for the federal system, 3 for the state system), the last three digits are the highway number,
3. The county number,
4. The control section code,
5. The section number within the control section,
6. The section length in miles.

TABLE 7. SAMPLE PAGE OF DETAILED OUTPUT OF PRIORITY MODEL

DIST.	HIGHWAY NUMBER	COUNTY NUMBER	CONTROL SECTION	SECTION NUMBER	SECTION LENGTH		PLAN 0	PLAN 1	PLAN 2	PLAN 3	PLAN 4
						ANNUAL ROAD-USER COST	16.1	0.0	15.6	0.0	0.0
						ANNUAL CAPITAL COST	0.0	0.0	8.7	0.0	0.0
1	3025	54	1	5	.44	BENEFIT COST RATIO	0.0	0.0	.1	0.0	0.0
						TOTAL CAPITAL COST	0.0	0.0	131.2	0.0	0.0
						RIGHT OF WAY NEED	SAME		NEW ROW		
						ANNUAL ROAD-USER COST	107.9	93.2	92.6	0.0	0.0
						ANNUAL CAPITAL COST	0.0	8.8	54.0	0.0	0.0
1	3025	54	1	6	2.72	BENEFIT COST RATIO	0.0	1.7	.3	0.0	0.0
						TOTAL CAPITAL COST	0.0	95.3	810.8	0.0	0.0
						RIGHT OF WAY NEED	SAME	SAME	NEW ROW		
						ANNUAL ROAD-USER COST	133.8	120.1	118.7	0.0	0.0
						ANNUAL CAPITAL COST	0.0	17.3	58.6	0.0	0.0
1	3025	79	2	1	4.73	BENEFIT COST RATIO	0.0	.8	.3	0.0	0.0
						TOTAL CAPITAL COST	0.0	187.2	882.6	0.0	0.0
						RIGHT OF WAY NEED	SAME	SAME	ADD. ROW		
						ANNUAL ROAD-USER COST	83.0	73.6	73.1	0.0	0.0
						ANNUAL CAPITAL COST	0.0	1.2	6.4	0.0	0.0
1	3025	79	2	2	.52	BENEFIT COST RATIO	0.0	7.5	1.5	0.0	0.0
						TOTAL CAPITAL COST	0.0	13.5	97.0	0.0	0.0
						RIGHT OF WAY NEED	SAME	SAME	ADD. ROW		
						ANNUAL ROAD-USER COST	2832.9	0.0	2547.8	0.0	0.0
						ANNUAL CAPITAL COST	0.0	0.0	236.5	0.0	0.0
1	3025	79	2	3	13.02	BENEFIT COST RATIO	0.0	0.0	1.2	0.0	0.0
						TOTAL CAPITAL COST	0.0	0.0	3519.3	0.0	0.0
						RIGHT OF WAY NEED	SAME		ADD. ROW		
						ANNUAL ROAD-USER COST	2074.2	0.0	0.0	0.0	1800.9
						ANNUAL CAPITAL COST	0.0	0.0	0.0	0.0	206.5
1	3025	79	2	14	4.55	BENEFIT COST RATIO	0.0	0.0	0.0	0.0	1.3
						TOTAL CAPITAL COST	0.0	0.0	0.0	0.0	3090.8
						RIGHT OF WAY NEED	SAME				NEW ROW
						ANNUAL ROAD-USER COST	2113.7	0.0	0.0	1893.9	0.0
						ANNUAL CAPITAL COST	0.0	0.0	0.0	243.8	0.0
1	3025	79	2	15	7.76	BENEFIT COST RATIO	0.0	0.0	0.0	.9	0.0
						TOTAL CAPITAL COST	0.0	0.0	0.0	3687.6	0.0
						RIGHT OF WAY NEED	SAME			NEW ROW	
						ANNUAL ROAD-USER COST	319.4	0.0	256.3	0.0	0.0
						ANNUAL CAPITAL COST	0.0	0.0	201.0	0.0	0.0
1	3026	86	1	1	7.84	BENEFIT COST RATIO	0.0	0.0	.3	0.0	0.0
						TOTAL CAPITAL COST	0.0	0.0	2993.3	0.0	0.0
						RIGHT OF WAY NEED	SAME		NEW ROW		
						ANNUAL ROAD-USER COST	135.9	0.0	104.9	0.0	0.0
						ANNUAL CAPITAL COST	10.6	0.0	191.5	0.0	0.0
1	3026	86	1	3	7.47	BENEFIT COST RATIO	0.0	0.0	.2	0.0	0.0
						TOTAL CAPITAL COST	78.2	0.0	2852.0	0.0	0.0
						RIGHT OF WAY NEED	SAME		NEW ROW		

Existing conditions were designated as plan 0. The four major improvement alternatives were designated as plans 1 to 4. Plan 1 is the reconstruction of highway sections, utilizing existing alignment when such improvement within the present right of way is feasible. Plans 2, 3 and 4 are not restricted to the present right of way. Partial or complete utilization of existing right of way is desirable, however, for such plans. If existing right of way is found obsolete, new right of way is programmed and its cost added to the total capital investment of the improvement. Plans 2, 3 and 4 also feature new ideal geometric alignments but they differ in the number of traffic lanes.

Traffic volumes at the design year on sections for which plan 2 is proposed do not exceed 7000 vpd and only two-lane roadways are programmed. Plan 3 is chosen for highway sections with the forecasted design traffic warranting four lane divided roadways while present and immediate future traffic are below such warrants. For plan 3, a two lane roadway is programmed for construction and adequate additional right of way is acquired and set aside for future expansion to a four lane divided highway. Plan 4 calls for the construction of a four-lane divided highway in one stage.

The five parameters chosen to summarize the economic analysis performed by the proposed model were listed in this order:

1. Annual Road-User Cost: This is the summation of the motor vehicles operating costs and the accident costs for the average year in the design period. The procedures for estimating all five parameters were detailed in Chapter IV and their definitions were given in Chapter III.

2. Annual Capital Cost: This is the annual investment cost of improvement, obtained by multiplying the various components of capital expenditures by the proper capital recovery factors.
3. Benefit Cost Ratio: This is the ratio that compares the road user benefits resulting from improvement to existing conditions. The Benefit-Cost ratio is not applicable for existing conditions and was listed by the computer as zero for plan 0.
4. Total Capital Cost: The summation of construction, bridge, right of way costs, etc. is the initial total capital cost. For existing conditions (plan 0) resurfacing of the present pavement, when necessary, is the only investment expenditure considered.
5. Right of Way Need: Three possible needs are diagnosed by the model and reported in the output; SAME indicates no right of way need, ADD. ROW indicates that additional partial right of way should be acquired, NEW recommends the relocation of the improvement on new right of way.

The model results were further summarized in records that contain the essential information of the priority analysis of each highway section. In addition to identification and location information of a highway section, a summary record listed the following:

1. The improvement plan with the highest benefit-cost return,
2. The right of way needs associated with the improvement plan,
3. The total capital cost of such improvement,
4. The benefit-cost ratio of this selected plan; this ratio serves as the priority rank of the respective highway section.

The summary records were sorted by district and decreasing order of the benefit-cost ratio (priority rank) for the highway sections of the Indiana rural state system considered in this investigation. The top forty projects (highest priority rank) in each district are presented in descending order of their priority rank in Tables 8 through 13.

Results

For Indiana rural state two-lane highways the results of applying the proposed benefit-cost economic analysis were logical and consistent. Careful examination of the forty projects with the highest priority rank in each highway district, summarized in Tables 8 through 13, reveals the following:

1. More than eighty percent of the selected projects were of the plan 1 type. Plan 1 is a limited improvement alternative. It involves the reconstruction of existing highways to adequate standards utilizing existing alignment and right of way. This is not hard to understand; widening existing pavement to the 24 foot standard and reconstructing some horizontal curves is all the improvement needed on many of the otherwise adequate highway sections in Indiana. More expensive improvement alternatives were found to be economically unjustified.
2. Only two projects with plan 4 as the recommended improvement alternative appear among the 240 most needed projects. Such absence is noticeable. It should be pointed out, however, that many of Indiana two-lane highway sections with heavy traffic and immediate need of conversion to four-lane divided

TABLE 8. SUMMARY BY DISTRICT AND PRIORITY OF IMPROVEMENTS REQUIRED OF INDIANA STATE HIGHWAYS — CRAWFORDSVILLE DISTRICT

HIGHWAY NUMBER	COUNTY NUMBER	CONTROL SECTION	SECTION NUMBER	SECTION LENGTH	TYPE OF IMPROVEMENT	RIGHT OF WAY	CAPITAL COST	BENEFIT-COST RATIO
U.S. 41	4	9	2	.68	PLAN 1	SAME	20.7	17.63
U.S. 36	32	4	6	4.60	PLAN 1	SAME	140.3	15.08
S.R. 25	79	2	2	.52	PLAN 1	SAME	13.5	7.51
S.R. 63	83	3	2	9.05	PLAN 1	SAME	275.9	6.54
S.R. 25	54	1	3	1.06	PLAN 1	SAME	37.1	6.34
U.S.421	12	8	3	.55	PLAN 1	SAME	14.3	6.30
U.S. 36	83	1	3	.83	PLAN 1	SAME	21.5	5.20
U.S.136	6	5	2	.47	PLAN 1	SAME	12.2	5.13
S.R.163	83	1	3	.20	PLAN 1	SAME	6.1	4.98
S.R. 28	12	4	1	6.86	PLAN 1	SAME	209.2	4.46
S.R. 28	79	3	6	.29	PLAN 1	SAME	9.8	3.62
U.S. 36	61	2	5	4.78	PLAN 1	SAME	196.4	3.61
S.R. 39	32	4	7	.82	PLAN 1	SAME	26.7	3.52
U.S.421	12	8	1	1.19	PLAN 1	SAME	28.5	2.55
S.R. 47	6	3	4	8.13	PLAN 1	SAME	248.5	2.29
S.R. 29	12	1	1	9.23	PLAN 2	SAME	1015.8	2.23
S.R. 39	32	4	10	2.26	PLAN 1	SAME	68.9	2.14
S.R. 47	6	3	3	4.28	PLAN 1	SAME	130.5	2.01
S.R. 39	6	5	1	8.01	PLAN 1	SAME	244.2	1.96
U.S.136	23	3	4	4.20	PLAN 3	NEW ROW	1095.8	1.96

TABLE 8. (CONTINUED)

HIGHWAY NUMBER	COUNTY NUMBER	CONTROL SECTION	SECTION NUMBER	SECTION LENGTH	TYPE OF IMPROVEMENT	RIGHT OF WAY	CAPITAL COST	BENEFIT-COST RATIO
U.S. 36	61	2	1	8.15	PLAN 2	NEW ROW	3111.7	1.90
S.R. 26	79	2	16	6.94	PLAN 2	ADD. ROW	1295.0	1.81
S.R. 75	6	4	4	3.10	PLAN 1	SAME	115.6	1.74
S.R.126	79	1	1	.21	PLAN 2	NEW ROW	80.2	1.70
S.R. 25	54	1	6	2.72	PLAN 1	SAME	95.3	1.67
S.R.341	23	1	6	5.60	PLAN 1	SAME	196.2	1.62
S.R. 55	4	4	6	8.31	PLAN 1	SAME	398.0	1.61
S.R.234	83	1	2	1.70	PLAN 1	SAME	59.6	1.51
S.R. 75	67	2	1	.16	PLAN 1	SAME	5.6	1.48
S.R. 42	55	5	3	6.31	PLAN 2	NEW ROW	2409.2	1.44
S.R. 47	54	2	11	10.34	PLAN 1	SAME	471.7	1.44
S.R. 59	61	4	1	10.91	PLAN 1	SAME	497.7	1.40
S.R. 25	79	2	14	4.55	PLAN 4	NEW ROW	3090.8	1.32
S.R. 55	4	4	2	.55	PLAN 2	NEW ROW	210.0	1.31
S.R.243	67	2	3	3.45	PLAN 1	SAME	188.7	1.27
U.S. 36	61	2	4	6.18	PLAN 2	ADD. ROW	1670.5	1.26
U.S. 41	23	7	3	3.50	PLAN 2	NEW ROW	1043.3	1.23
S.R. 25	79	2	3	13.02	PLAN 2	ADD. ROW	3514.3	1.21
S.R.236	32	3	1	2.76	PLAN 1	SAME	71.6	1.21
S.R.240	67	1	2	9.02	PLAN 2	ADD. ROW	1683.1	1.21
S.R. 43	54	6	2	6.88	PLAN 2	NEW ROW	2050.9	1.18

TABLE 9. SUMMARY BY DISTRICT AND PRIORITY OF IMPROVEMENTS REQUIRED OF INDIANA STATE HIGHWAYS — FORT WAYNE DISTRICT

HIGHWAY NUMBER	COUNTY NUMBER	CONTROL SECTION	SECTION NUMBER	SECTION LENGTH	TYPE OF IMPROVEMENT	RIGHT OF WAY	CAPITAL COST	BENEFIT-COST RATIO
S.R. 5	92	2	3	.69	PLAN 1	SAME	17.9	24.46
S.R.427	76	2	1	.37	PLAN 1	SAME	9.6	19.04
S.R. 15	20	4	13	.22	PLAN 1	SAME	6.7	17.59
S.R. 13	85	4	6	1.13	PLAN 1	SAME	34.5	11.09
S.R. 15	20	4	11	4.90	PLAN 1	SAME	171.6	9.37
S.R. 15	85	2	2	6.32	PLAN 1	SAME	192.7	7.82
S.R. 13	27	3	5	5.29	PLAN 1	SAME	161.3	6.84
U.S.224	35	1	3	.78	PLAN 1	SAME	20.2	6.28
S.R. 13	85	4	7	5.75	PLAN 1	SAME	175.3	6.14
U.S.224	1	3	6	2.75	PLAN 1	SAME	83.8	5.89
S.R. 13	85	4	8	6.06	PLAN 1	SAME	184.8	5.82
U.S. 33	20	5	1	1.55	PLAN 1	SAME	57.8	5.56
S.R.114	85	5	2	5.05	PLAN 1	SAME	154.0	5.33
S.R. 18	27	6	9	2.20	PLAN 1	SAME	77.1	5.27
U.S. 24	2	9	17	2.41	PLAN 1	SAME	99.0	5.23
S.R.205	92	1	5	.58	PLAN 1	SAME	20.3	5.13
S.R. 3	35	11	3	.40	PLAN 1	SAME	10.4	5.04
U.S. 24	2	9	16	10.31	PLAN 3	ADD. ROW	1297.0	4.80
S.R.127	76	1	8	1.16	PLAN 3	ADD. ROW	145.9	4.53
S.R. 9	35	6	2	.79	PLAN 1	SAME	24.1	4.50

TABLE 9. (CONTINUED)

HIGHWAY NUMBER	COUNTY NUMBER	CONTROL SECTION	SECTION NUMBER	SECTION LENGTH	TYPE OF IMPROVEMENT	RIGHT OF WAY	CAPITAL COST	BENEFIT-COST RATIO
U.S. 33	57	4	9	2.51	PLAN 1	SAME	108.7	4.36
S.R. 1	2	8	17	11.39	PLAN 1	SAME	519.6	4.09
S.R. 13	85	4	1	5.98	PLAN 1	SAME	182.3	3.94
S.R.120	76	3	3	1.91	PLAN 1	SAME	66.9	3.91
S.R. 9	35	6	3	3.82	PLAN 1	SAME	116.5	3.78
U.S. 33	20	5	2	.77	PLAN 1	SAME	33.4	3.71
U.S. 33	20	5	3	4.15	PLAN 1	SAME	126.5	3.40
U.S. 20	20	5	8	4.48	PLAN 3	ADD. ROW	563.6	3.26
S.R.114	85	5	1	3.04	PLAN 1	SAME	92.7	3.24
S.R.218	1	7	2	4.55	PLAN 1	SAME	138.7	3.16
U.S. 6	17	8	6	1.47	PLAN 1	SAME	38.1	3.11
S.R. 5	44	4	1	8.97	PLAN 1	SAME	334.6	3.06
U.S. 20	20	5	9	6.17	PLAN 2	SAME	676.8	3.02
S.R. 14	2	7	18	3.40	PLAN 1	SAME	139.7	2.93
S.R. 14	25	4	12	.53	PLAN 1	SAME	16.9	2.92
S.R.120	44	2	4	4.80	PLAN 1	SAME	157.2	2.89
S.R.120	20	1	7	1.28	PLAN 1	SAME	47.7	2.81
S.R.116	90	2	12	1.44	PLAN 1	SAME	59.1	2.77
S.R. 18	52	5	4	.49	PLAN 1	SAME	12.7	2.70
S.R. 14	43	5	3	3.00	PLAN 1	SAME	123.1	2.69
S.R.124	90	4	7	1.07	PLAN 1	SAME	37.5	2.68

TABLE 10. SUMMARY BY DISTRICT AND PRIORITY OF IMPROVEMENTS REQUIRED OF INDIANA STATE HIGHWAYS – GREENFIED DISTRICT

HIGHWAY NUMBER	COUNTY NUMBER	CONTROL SECTION	SECTION NUMBER	SECTION LENGTH	TYPE OF IMPROVEMENT	RIGHT OF WAY	CAPITAL COST	BENEFIT-COST RATIO
S.R. 13	30	1	5	.40	PLAN 1	SAME	10.4	53.29
S.R. 32	29	5	6	.30	PLAN 1	SAME	9.1	45.97
S.R.232	48	1	3	.93	PLAN 1	SAME	28.4	24.52
S.R. 67	48	8	4	.16	PLAN 1	SAME	4.2	14.80
S.R. 9	27	5	4	.74	PLAN 1	SAME	22.6	12.64
S.R. 28	48	6	3	.82	PLAN 1	SAME	25.0	11.64
S.R. 9	27	5	3	2.24	PLAN 1	SAME	68.3	10.72
S.R. 13	48	2	8	1.04	PLAN 1	SAME	52.2	10.63
S.R. 32	29	5	3	.30	PLAN 1	SAME	7.8	10.52
S.R.236	48	4	2	2.18	PLAN 1	SAME	86.3	9.72
S.R. 67	30	7	3	.31	PLAN 1	SAME	8.0	9.40
S.R. 3	33	7	2	4.41	PLAN 1	SAME	201.2	9.11
S.R. 32	29	5	8	6.25	PLAN 1	SAME	190.6	9.11
S.R. 28	48	6	4	7.09	PLAN 1	SAME	216.2	9.01
S.R.140	33	2	1	.58	PLAN 1	SAME	15.1	7.75
S.R. 28	18	7	5	1.59	PLAN 1	SAME	41.3	7.23
U.S. 27	81	1	3	.06	PLAN 1	SAME	2.5	7.17
S.R. 32	68	8	1	4.74	PLAN 1	SAME	194.7	6.89
S.R. 67	38	10	1	4.91	PLAN 1	SAME	149.7	6.52
S.R. 26	38	7	4	.98	PLAN 1	SAME	40.3	6.32

TABLE 10. (CONTINUED)

HIGHWAY NUMBER	COUNTY NUMBER	CONTROL SECTION	SECTION NUMBER	SECTION LENGTH	TYPE OF IMPROVEMENT	RIGHT OF WAY	CAPITAL COST	BENEFIT-COST RATIO
S.R. 22	27	3	10	2.50	PLAN 1	SAME	76.2	6.30
S.R. 32	68	8	7	1.70	PLAN 1	SAME	59.6	6.24
S.R. 38	48	5	1	1.05	PLAN 1	SAME	36.9	5.61
S.R. 38	48	5	5	5.67	PLAN 1	SAME	172.9	5.53
U.S. 31	29	7	6	1.29	PLAN 1	SAME	33.5	5.23
S.R. 19	80	2	1	3.77	PLAN 1	SAME	132.1	4.99
S.R.236	48	4	3	.90	PLAN 1	SAME	35.6	4.81
S.R. 44	41	2	7	2.93	PLAN 1	SAME	115.9	4.64
S.R. 38	48	5	6	3.21	PLAN 1	SAME	97.9	4.53
U.S. 35	89	1	7	15.08	PLAN 1	SAME	619.5	4.36
S.R. 26	27	5	4	.83	PLAN 1	SAME	29.1	4.24
S.R. 18	5	7	2	4.99	PLAN 1	SAME	205.0	4.14
S.R. 28	68	8	2	9.77	PLAN 1	SAME	445.7	3.96
U.S. 35	27	5	8	2.12	PLAN 1	SAME	64.6	3.92
S.R. 37	29	9	3	6.88	PLAN 3	ADD. ROW	865.5	3.82
S.R.109	48	3	2	1.57	PLAN 1	SAME	55.0	3.70
S.R. 32	18	7	1	.67	PLAN 1	SAME	17.4	3.45
S.R. 18	5	7	3	4.10	PLAN 1	SAME	143.6	3.24
S.R.234	30	8	2	3.10	PLAN 1	SAME	108.6	3.22
S.R.140	70	1	1	1.67	PLAN 1	SAME	58.5	3.15
U.S. 27	81	1	2	.44	PLAN 2	NEW ROW	131.2	3.03

TABLE II. SUMMARY BY DISTRICT AND PRIORITY OF IMPROVEMENTS REQUIRED OF INDIANA STATE HIGHWAYS — LA PORTE DISTRICT

HIGHWAY NUMBER	COUNTY NUMBER	CONTROL SECTION	SECTION NUMBER	SECTION LENGTH	TYPE OF IMPROVEMENT	RIGHT OF WAY	CAPITAL COST	BENEFIT-COST RATIO
U.S. 6	71	4	3	.14	PLAN 1	SAME	3.6	68.90
S.R. 53	64	4	3	.15	PLAN 1	SAME	3.9	28.63
U.S. 20	46	3	12	3.35	PLAN 1	SAME	122.3	25.45
S.R. 49	64	2	12	.65	PLAN 1	SAME	22.8	14.93
S.R. 10	75	3	4	2.05	PLAN 1	SAME	62.5	11.72
U.S. 35	66	8	2	.58	PLAN 1	SAME	15.1	50.39
S.R. 2	46	3	2	.90	PLAN 1	SAME	31.5	10.37
S.R.123	71	1	1	1.49	PLAN 1	SAME	52.2	9.13
U.S.421	8	9	6	2.50	PLAN 1	SAME	97.6	8.78
U.S. 35	75	9	7	5.45	PLAN 1	SAME	166.2	8.71
U.S. 35	9	7	3	6.44	PLAN 1	SAME	196.4	8.69
U.S.421	75	12	3	3.55	PLAN 1	SAME	108.2	8.38
U.S. 24	52	5	1	2.13	PLAN 1	SAME	64.9	8.22
U.S.421	91	10	1	.30	PLAN 1	SAME	10.5	8.13
U.S. 24	91	3	3	5.14	PLAN 1	SAME	156.7	8.09
U.S. 35	66	8	3	.14	PLAN 1	SAME	5.8	8.07
U.S.421	46	13	5	.85	PLAN 1	SAME	22.1	7.71
U.S. 35	75	9	3	6.57	PLAN 1	SAME	299.7	6.92
S.R. 53	37	3	9	2.25	PLAN 1	SAME	68.6	6.24
U.S. 24	91	3	8	.86	PLAN 1	SAME	35.3	5.07

TABLE II. (CONTINUED)

HIGHWAY NUMBER	COUNTY NUMBER	CONTROL SECTION	SECTION NUMBER	SECTION LENGTH	TYPE OF IMPROVEMENT	RIGHT OF WAY	CAPITAL COST	BENEFIT-COST RATIO
U.S.421	75	12	2	2.02	PLAN 1	SAME	92.2	5.48
S.R. 53	37	3	3	4.10	PLAN 1	SAME	152.9	5.08
S.R. 16	56	1	2	4.01	PLAN 1	SAME	122.3	4.75
S.R. 4	46	1	2	5.32	PLAN 1	SAME	242.7	4.55
S.R. 25	25	5	10	.32	PLAN 1	SAME	11.2	4.54
U.S. 31	50	12	1	4.65	PLAN 3	ADD. ROW	585.0	4.44
U.S. 24	56	1	4	.50	PLAN 1	SAME	13.0	4.09
S.R. 17	50	3	4	7.60	PLAN 1	SAME	346.7	3.85
U.S. 35	46	10	10	3.56	PLAN 3	ADD. ROW	447.8	3.77
U.S. 20	71	4	1	9.78	PLAN 2	SAME	1072.9	3.69
U.S. 24	56	1	2	2.84	PLAN 1	SAME	73.7	3.57
U.S.421	91	10	8	9.07	PLAN 1	SAME	235.4	3.56
S.R. 53	37	3	2	6.91	PLAN 1	SAME	257.7	3.48
S.R. 10	37	2	4	5.58	PLAN 1	SAME	195.5	3.29
S.R. 8	75	4	1	.43	PLAN 1	SAME	15.1	3.28
S.R. 23	71	2	1	2.58	PLAN 1	SAME	129.4	3.25
S.R. 39	75	10	1	3.00	PLAN 1	SAME	105.1	3.25
S.R. 23	71	2	4	4.14	PLAN 1	SAME	107.4	3.24
S.R. 2	46	3	4	9.19	PLAN 3	ADD. ROW	1156.1	3.22
S.R. 18	8	3	7	6.05	PLAN 1	SAME	211.9	3.22
U.S. 31	25	11	1	7.05	PLAN 3	ADD. ROW	886.9	3.20

TABLE 12. SUMMARY BY DISTRICT AND PRIORITY OF IMPROVEMENTS REQUIRED OF INDIANA STATE HIGHWAYS — SEYMOUR DISTRICT

HIGHWAY NUMBER	COUNTY NUMBER	CONTROL SECTION	SECTION NUMBER	SECTION LENGTH	TYPE OF IMPROVEMENT	RIGHT OF WAY	CAPITAL COST	BENEFIT-COST RATIO
S.R. 39	55	3	2	.45	PLAN 1	SAME	13.7	43.06
S.R. 37	55	6	1	5.13	PLAN 1	SAME	156.4	19.05
U.S. 31	3	4	2	.42	PLAN 1	SAME	12.8	16.43
S.R.135	55	5	2	.65	PLAN 1	SAME	16.9	16.34
U.S. 31	72	2	2	1.00	PLAN 1	SAME	30.5	12.83
S.R. 45	53	8	1	9.21	PLAN 1	SAME	420.2	10.06
U.S. 50	36	5	6	9.18	PLAN 1	SAME	377.1	9.19
U.S. 31	3	4	3	3.23	PLAN 1	SAME	98.5	8.78
U.S. 31	72	2	10	1.08	PLAN 1	SAME	32.9	8.34
S.R. 46	53	4	8	.50	PLAN 1	SAME	13.0	8.24
U.S. 52	15	12	2	.35	PLAN 1	SAME	9.1	8.06
U.S. 50	40	6	1	9.73	PLAN 1	SAME	399.7	7.67
S.R. 62	10	11	12	16.00	PLAN 1	SAME	657.3	7.60
U.S.421	69	2	3	.49	PLAN 1	SAME	12.7	7.47
S.R.135	88	2	8	12.25	PLAN 1	SAME	558.8	6.69
S.R. 48	53	4	1	5.16	PLAN 1	SAME	258.8	6.29
U.S.150	22	9	1	1.81	PLAN 1	SAME	55.2	6.00
S.R. 56	78	8	2	1.50	PLAN 1	SAME	38.9	5.92
S.R. 44	41	2	3	.46	PLAN 1	SAME	16.1	5.79
S.R. 37	55	6	4	.61	PLAN 1	SAME	15.8	5.52

TABLE 12. (CONTINUED)

HIGHWAY NUMBER	COUNTY NUMBER	CONTROL SECTION	SECTION NUMBER	SECTION LENGTH	TYPE OF IMPROVEMENT	RIGHT OF WAY	CAPITAL COST	BENEFIT-COST RATIO
S.R.252	55	1	2	9.52	PLAN 1	SAME	477.5	5.39
S.R.144	41	2	1	.21	PLAN 1	SAME	5.4	5.29
S.R.252	41	2	4	.57	PLAN 1	SAME	20.0	5.22
S.R. 9	73	2	1	10.62	PLAN 1	SAME	372.0	5.12
S.R. 56	72	6	5	2.75	PLAN 1	SAME	96.3	4.79
U.S. 31	36	1	4	1.10	PLAN 1	SAME	33.5	4.46
S.R. 67	60	3	5	6.36	PLAN 3	ADD. ROW	900.1	3.67
S.R.256	72	3	1	1.40	PLAN 1	SAME	49.0	3.67
S.R. 46	3	6	1	6.49	PLAN 3	ADD. ROW	916.4	3.65
U.S. 31	72	2	7	2.74	PLAN 1	SAME	71.1	3.58
S.R.144	41	2	2	4.76	PLAN 1	SAME	166.7	3.51
S.R. 46	15	10	2	.61	PLAN 1	SAME	21.4	3.24
U.S. 31	72	2	1	3.10	PLAN 1	SAME	94.5	3.11
S.R.252	41	2	6	.26	PLAN 1	SAME	9.1	3.00
S.R. 46	3	6	14	6.15	PLAN 1	SAME	308.5	2.97
S.R. 46	16	7	1	6.92	PLAN 1	SAME	347.1	2.61
S.R. 62	39	12	4	.19	PLAN 3	NEW ROW	90.3	2.59
S.R.252	41	2	2	8.71	PLAN 1	SAME	265.6	2.46
S.R. 46	7	5	1	9.01	PLAN 2	ADD. ROW	3189.5	2.39
S.R. 46	69	9	4	1.60	PLAN 1	SAME	56.0	2.36
S.R.135	31	1	1	.42	PLAN 1	SAME	10.9	2.34

TABLE 13. SUMMARY BY DISTRICT AND PRIORITY OF IMPROVEMENTS REQUIRED OF INDIANA STATE HIGHWAYS — VINCENNES DISTRICT

HIGHWAY NUMBER	COUNTY NUMBER	CONTROL SECTION	SECTION NUMBER	SECTION LENGTH	TYPE OF IMPROVEMENT	RIGHT OF WAY	CAPITAL COST	BENEFIT-COST RATIO
S.R. 67	28	2	4	.04	PLAN 1	SAME	1.0	31.58
S.R. 62	87	5	1	1.68	PLAN 1	SAME	51.2	27.72
S.R. 37	47	4	2	.76	PLAN 1	SAME	23.2	17.22
S.R. 54	28	2	2	1.28	PLAN 1	SAME	46.7	16.65
S.R. 37	47	4	3	5.81	PLAN 1	SAME	177.1	11.17
S.R. 67	28	2	3	3.29	PLAN 1	SAME	100.3	9.95
S.R. 56	63	2	6	4.08	PLAN 1	SAME	124.4	9.87
S.R.662	82	1	2	.49	PLAN 1	SAME	22.4	9.17
U.S. 50	42	1	5	.64	PLAN 1	SAME	16.6	9.04
S.R. 66	65	1	2	1.56	PLAN 1	SAME	51.1	6.34
S.R. 57	87	3	2	.52	PLAN 1	SAME	13.5	6.13
S.R. 64	26	1	9	1.06	PLAN 1	SAME	41.1	6.85
S.R.237	62	1	1	.38	PLAN 1	SAME	9.9	6.51
S.R. 66	74	4	5	5.09	PLAN 1	SAME	155.2	4.80
S.R. 37	59	3	7	1.67	PLAN 1	SAME	43.3	4.75
S.R. 60	88	3	1	11.08	PLAN 1	SAME	337.8	4.70
S.R. 60	47	1	3	7.52	PLAN 1	SAME	229.3	4.12
S.R.145	59	4	1	12.02	PLAN 1	SAME	602.9	3.81
S.R. 66	62	5	2	2.91	PLAN 3	ADD. ROW	366.1	3.80
S.R. 57	26	4	2	5.26	PLAN 3	ADD. ROW	661.7	3.62

TABLE 13. (CONTINUED)

HIGHWAY NUMBER	COUNTY NUMBER	CONTROL SECTION	SECTION NUMBER	SECTION LENGTH	TYPE OF IMPROVEMENT	RIGHT OF WAY	CAPITAL COST	BENEFIT-COST RATIO
S.R. 45	28	7	3	7.63	PLAN 1	SAME	348.1	3.31
S.R. 58	14	3	4	9.05	PLAN 1	SAME	275.9	3.29
S.R. 60	59	2	1	3.74	PLAN 1	SAME	114.0	3.27
S.R. 45	28	7	2	9.10	PLAN 1	SAME	456.5	3.22
S.R. 66	62	5	1	.69	PLAN 1	SAME	17.9	2.49
S.R. 66	87	3	1	3.25	PLAN 1	SAME	99.1	2.45
U.S.150	59	6	8	9.93	PLAN 2	ADD. ROW	3515.2	2.00
S.R. 48	11	2	1	.39	PLAN 1	SAME	13.7	1.93
S.R.558	14	1	1	2.06	PLAN 1	SAME	84.6	1.92
S.R.257	63	1	4	2.16	PLAN 1	SAME	118.2	1.88
S.R. 57	63	5	1	8.19	PLAN 2	SAME	1583.9	1.80
S.R.662	87	2	1	2.72	PLAN 4	NEW ROW	1447.7	1.73
S.R. 67	60	3	1	12.55	PLAN 3	NEW ROW	5063.8	1.72
U.S.150	59	6	2	7.56	PLAN 2	NEW ROW	2886.4	1.67
S.R. 54	28	2	8	11.78	PLAN 2	NEW ROW	4497.6	1.62
S.R. 65	82	1	1	11.08	PLAN 2	NEW ROW	4230.3	1.59
S.R. 68	26	2	1	7.71	PLAN 1	SAME	235.1	1.59
S.R.662	87	2	2	1.83	PLAN 2	NEW ROW	698.7	1.57
U.S. 50	51	3	8	1.54	PLAN 3	NEW ROW	960.7	1.54
S.R.245	74	1	3	9.05	PLAN 1	SAME	453.9	1.54
S.R.356	63	1	2	9.12	PLAN 1	SAME	498.9	1.48

facilities are already included in one of the Commission's three programming phases. These programs include extensive mileage of U.S. 30, U.S. 31, U.S. 41 and S.R. 67. Highway sections that are already in the programming phase were excluded from this priority analysis.

3. A large number of the highest priority projects in each district have the following properties: short section length, low total capital cost, and very high benefit cost ratio. Many of these short sections occur near boundaries of urban areas. They usually include an intersection. Rebuilding such intersections by adding turning lanes within existing right of way is often the reconstruction required and is inexpensive. Appreciable savings due to accident reduction coupled with the low improvement cost account for the high benefit cost ratio.

A value of six percent interest rate was chosen for the economic analysis as explained earlier. To resolve arguments calling for different interest rates, the analysis was repeated using seven percent interest, and the results of the two applications were compared. This partial sensitivity analysis revealed that the priority ranking is not sensitive to values of the interest rate in the range under consideration. More specifically, comparing the summary Tables 8 through 13 with their counterparts of the seven percent interest rate analysis (these tables are not included in this manuscript) enforced this claim. The following were observed:

1. The priority ranks (benefit-cost ratio) of the seven percent analysis, as expected, were slightly less than their six percent counterparts.
2. In the Crawfordsville district 39 of the 40 top ranked projects of the six percent interest rate analysis appeared in the top 40 ranked projects of the seven percent analysis. In the remaining five districts the same forty projects of each district were included in both lists respectively.
3. The order of projects in both lists was nearly identical. In the Crawfordsville district, for example, the first 23 projects were in the same sequence (priority rank) in both analyses. In the Fort Wayne, Greenfield, LaPorte, Seymour and Vincennes districts the exact sequencing of projects on the two lists spanned the first 17, 33, 28, 26 and 20 projects respectively.

With a changing economic climate and interest rates this demonstrated stability of the economic model is another added advantage of the proposed technique.

The economic priority analysis was also used to estimate the highway needs of Indiana rural state highways. Highway sections were classified into five groups according to their priority rank (benefit-cost ratio score). The description of the five groups and their range is as follows:

Priority Group Type	Benefit-Cost Ratio Range
Immediate Need	Above 4.0
High Priority	4.0 - 2.0
Moderate Priority	2.0 - 1.5
Low Priority	1.5 - 1.0
Adequate (No Need for Improvement)	Less than 1.0

Table 14 summarizes the following statistics; the total length, total improvement cost and improvement cost per mile of sections in the four priority groups; and the total length of highway sections rated adequate (no need for improvement). The listings in Table 14 are also classified by the highway district and for all districts. It is easy to note that as the priority group decreases the total length of deficient sections in that group increases, the total costs of improvements for that group increases and the costs per mile increases. The length of sections in immediate need in all districts, for example, are 398.66 miles; the length of sections in the low priority group, on the other hand, are 1167.39 miles. The statewide average cost of improvements per mile for the immediate priority group is estimated as $39,400 while that of the next group, high priority, is $82,800. The cost of rebuilding all sections in the immediate need group is slightly above fifteen million dollars while that of the low priority group is more than two hundred and seventy five million dollars.

The length of the rural highway system in Indiana at the time of this study was 9775.13 miles. Only 8457.80 miles were analyzed in this investigation. The remaining highway sections were either four-lane

PRIORITY GROUP - B/C RATIO RANGE	VINCENNES DISTRICT	ALL DISTRICTS
Above 4.00	46.89	398.66
	1,444,100	15,709,500
	30,800	39,400
4.00-2.00	63.58	647.81
	6,457,400	53,615,000
	101,600	82,800
2.00-1.50	78.62	534.73
	23,474,600	88,880,200
	208,600	166,200
1.50-1.00	118.97	1167.39
	28,041,800	275,657,400
	235,700	236,100
Less Than 1.00	1228.00	5709.21

TABLE 14. SUMMARY BY DISTRICTS AND PRIORITY OF IMPROVEMENTS REQUIRED OF INDIANA STATE RURAL HIGHWAYS

PRIORITY GROUP - B/C RATIO RANGE		CRAWFORDSVILLE DISTRICT	FORT WAYNE DISTRICT	GREENFIELD DISTRICT	LAPORTE DISTRICT	SEYMOUR DISTRICT	VINCENNES DISTRICT	ALL DISTRICTS
Above 4.00	Length of Deficient Sections	24.82	72.61	83.95	66.41	103.98	46.89	398.66
	Total Cost of Improvements	750,800	3,572,300	2,988,000	2,755,200	4,199,100	1,444,100	15,709,500
	Improvement Cost Per Mile	30,200	49,200	35,600	41,500	40,400	30,800	39,400
4.00-2.00	Length of Deficient Sections	30.93	132.04	118.52	205.46	97.28	63.58	647.81
	Total Cost of Improvements	1,727,100	10,365,400	10,940,400	9,926,500	14,198,200	6,457,400	53,615,000
	Improvement Cost Per Mile	55,800	78,500	92,300	48,300	146,000	101,600	82,800
2.00-1.50	Length of Deficient Sections	48.94	132.66	90.54	112.00	71.97	78.62	534.73
	Total Cost of Improvements	7,591,600	14,294,800	15,175,800	7,922,500	20,420,900	23,474,600	88,880,200
	Improvement Cost Per Mile	155,100	107,800	167,600	70,700	283,700	298,600	166,200
1.50-1.00	Length of Deficient Sections	171.97	376.69	111.58	212.55	175.63	118.97	1167.39
	Total Cost of Improvements	39,686,700	85,379,500	32,344,700	32,173,100	58,031,600	28,041,800	275,657,400
	Improvement Cost Per Mile	230,800	226,700	289,900	151,400	330,400	235,700	236,100
Less Than 1.00	Length of Sections	1049.90	881.85	827.11	708.88	1013.47	1228.00	5709.21

facilities or included in one of the Commission's planned improvement programs. It is interesting to note that only 398.66 miles of highway were rated as deficient and in immediate need of improvement. On the other hand 5709.21 miles were rated as adequate. It could be concluded that Indiana's rural state highway system is providing in general satisfactory, adequate service.

The results of the application are presented for information. The economic priority analysis is a recommended first step in the ISHC programming process. Its success will be measured by its acceptance by the "programmer" as a tool that aids him in reaching sound programming decisions.

CHAPTER VI. CONCLUSIONS AND FURTHER RESEARCH

Conclusions

This research investigation was concerned with the development of an economic approach to priority programming. The concept of using benefit-cost analysis for priority programming is simple. Formulating, programming and applying the concept is similarly uncomplicated. The model was completely developed and successfully applied to a large portion of the Indiana highway system. Furthermore, the time duration, manpower employed and the cost of this investigation were reasonably low. Such advantages and desirable features should make similar studies elsewhere highly feasible.

This research dealt with topics for which few published results were available. Considerable effort was spent quantifying cost values and decision parameters. The range of application of the quantification results cover many aspects of highway engineering practice and should benefit similar applications of the proposed benefit-cost analysis approach. The following results are the main features of the quantification process:

1. Travel time is an essential parameter in evaluating the level of service provided by a highway facility, the adequacy of a highway system, road-user costs, and the magnitude of improvements needed. Developing a model to estimate travel time on two lane rural highways was a task of this research

effort. A regression model containing only six independent variables (which measure the effects of traffic, geometric features and pavement conditions) predicted average operating speeds with a high degree of accuracy. The range of application of this model covers a large area of transportation engineering.

2. A comprehensive accident study for Indiana rural state highways using the accidents reported in 1967-68 was another phase of this research investigation. Accidents were analyzed statistically and classified into groups based on severity, exposure, vehicle type, etc. and the characteristic features of accidents in each group were examined. The direct cost of reported accidents ($ 1970) was evaluated for different severity groups and the cost of unreported accidents was estimated. The average cost of a reported accident was found to be $2433. In addition to the use of the above results in the devised priority programming procedure, these findings are of great interest and value in almost every area of highway and traffic safety.

3. In a complimentary work to the accident study, the accident costs on highway sections improved to ideal or adequate standards were evaluated. This offers a tool for measuring an important benefit resulting from highway improvements, the reduction in the number of accidents. Sizeable reductions in accident costs through new highway construction are often the major justification of improvement projects.

4. A detailed study of capital expenditures on Indiana rural state highways was conducted when a literature search did not produce any aid for evaluating capital costs of improvement alternatives. Four different phases of highway construction, identified as separate activities, were: roadway construction, roadway reconstruction, roadway maintenance and bridge construction. Separate analysis was performed on a sample of contracts for each type of highway construction. Multiple linear regression was the chosen method of analysis. The desirable statistical qualities of regression analysis, the purpose of the evaluation process and the structure of the information available combined to produce four models of high quality. Each model accounted separately for inflation; of many parameters used in the analysis, only the significant ones were retained as descriptors of the various expenditures. The four models are:

   a. Roadway Construction: The dependent variable is construction cost per mile. Ten independent variables describe the various activities of two or four-lane highway construction.

   b. Roadway Reconstruction: The dependent variable is reconstruction cost per mile of roadway. Five independent variables are included to describe the cost of rebuilding deficient highways to adequate standards.

c. Roadway Maintenance: The cost of pavement resurfacing is the only activity described by this model. Five independent variables are included to measure the cost of resurfacing per mile of highway.

d. Bridge Construction: The cost of constructing one bridge is the independent variable. The six independent variables selected by the regression analysis described the features of the bridge.

The models were used in the benefit-cost ratio priority model. Their accurate power as first estimates of highway construction should encourage their direct application or similar use of the analysis technique in related planning activities.

As noted earlier the application of the proposed approach as a priority tool for Indiana rural state two-lane highways was successful, logical and consistent. Actual field checks on some of the high priority sections were undertaken. The sections were deficient and the immediate need for improvements was obvious. An overall examination of the results indicated that the Indiana rural state highway system is providing, in general, satisfactory, adequate service. Finally, the proposed economic priority analysis using the benefit-cost ratio is recommended for inclusion in the ISHC programming process.

Recommendations for Further Research

The economic priority model, which was formulated in this investigation, covers several areas related to traffic engineering and highway planning. Although this technique has been developed to an operational stage in this study and applied successfully to the

Indiana rural state highway system, further research is needed to refine some phases of data collection, planning studies and the developed model itself. The following further research is recommended:

1. The proposed benefit-cost analysis model, like any other priority rating procedure, uses the highway inventory as a main source of input data. A considerable portion of inventory information is of little or no use to priority programming because of the way the data were collected and/or coded; some information is irrelevant and perhaps should not be included; and some other information which would be of value is completely missing. Many of these drawbacks could be rectified if the inventory survey would be reevaluated. A critical review of inventory survey practice to place each item on a functional basis is desirable.
2. Past experience is the best aid to future decisions. The use of financial expenditure records in fiscal planning and highway economics is a vital necessity. Unfortunately, present filing and/or recording practices of highway expenditures in many agencies make the determination of highway expenditures on a section of highway by functional item very difficult. A study investigation into the techniques of reporting and recording highway expenditures should be undertaken.
3. The analysis of the needs of county roads and the establishment of a priority program for those needs is another opportunity to apply the benefit-cost analysis approach. Such application

should be performed separately by county road systems to insure a more accurate evaluation of the cost parameters and a stronger feedback into the results.

4. Significant improvements in the highway service of urban arterials are achieved by proper application of traffic operation techniques and redesigns of intersection layouts. this is the essence of the TOPICS program. A quantitative rather than qualitative measure of such improvements could be achieved by applying the concepts of this study.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. Road-User Benefit Analyses for Highway Improvements, Part I, "Passenger Cars in Rural Areas", American Association of State Highway Officials, Washington, D. C., 1960.

2. Baerwald, J. E., "Improvement Priority Rating for Local Rural Roads in Indiana", Proceedings, 35th Annual Meeting, Highway Research Board, Washington, D. C., 1965.

3. Billingsley, C. M., and D. D. Jorgenson, "Analysis of Direct Costs and Frequencies of Illinois Motor Vehicle Accidents, 1958", Public Roads, Vol. 32, No. 9, August 1963.

4. Campbell, M. E., "Elemental Versus Composite Ratings", Highway Research Board Bulletin 53, Washington, D. C., 1952.

5. Campbell, M. E., "Physical and Economic Rating Methods for Priority Considerations", Highway Research Board, Special Report 62, Washington, D. C., 1961.

6. Claffey, P. J., "Characteristics of Passenger Car Travel on Toll Roads and Comparable Free Roads", Highway Research Board Bulletin 306, Washington, D. C., 1961.

7. Cleveland, D. E., Manual of Traffic Engineering Studies, Institute of Traffic Engineers, Washington, D. C., 1964.

8. "A Review of Scheduling Procedures for State Highway Construction Programs", Highway Research Board Committee on Highway Programming, H.R.R. 32, Highway Research Board, Washington, D. C., 1963.

9. Cooper, F., "Perpetual Highway Needs Study", Highway Research Board Bulletin 158, Washington, D. C., 1957.

10. Cost of Motor Vehicle Accidents to Illinois Motorists, 1958, State of Illinois, Department of Public Works and Buildings, Division of Highways, 1962.

11. Covault, D. O., "Indiana Highway Needs Study", Highway Research Board Bulletin 194, Washington, D. C., 1958.

12. Covault, D. O., and H. L. Michael, "Estimation of County Primary Road System Needs by Sample Survey Methods", Highway Research Board Bulletin 249, Washington, D. C., 1960.

13. Dixon, W. J., BMD-Biomedical Computer Programs, University of California Press, 1968.

14. Donnell, P. M., and S. T. Lawrence, "Priorities Determination and Programming in Tennessee", Highway Research Board Bulletin 158, Washington, D. C., 1957.

15. Donnell, P. M., "Tennessee Programming Study: First Year Experience and Techniques for Updating", Highway Research Board Bulletin 194, Washington, D. C., 1958.

16. Drake, G. L., and M. A. Kraft, "Motor-Vehicle Accident Costs in the Washington Metropolitan Area", H.R.R. 188, Highway Research Board, Washington, D. C., 1967.

17. Draper, N. R., and H. Smith, Applied Regression Analysis, John Wiley & Sons, Inc., New York, 1966.

18. Dunman, R., "The Economic Cost of Motor Vehicle Accidents of Different Type", Public Roads, Vol. 30, No. 2, June 1958.

19. England, A. C., "Balancing of Physical and Economic Ratings with Other Considerations to Establish Project Priorities", Highway Research Board, Special Report 62, Washington, D. C., 1961.

20. Fritts, C. E., "Relation of Sufficiency Ratings, Tolerable Standards and Priorities", Highway Research Board Bulletin 53, Washington, D. C., 1952.

21. Gardner, E. H., "The Congestion Approach to Rational Programming", Highway Research Board Bulletin 249, Washington, D. C., 1960.

22. Gardner, E. H., and J. B. Chiles, "Sufficiency Rating by Investment Opportunity", H.R.R. 87, Highway Research Board, Washington, D. C., 1965.

23. Granum, J. O., "Highway Program Evaluation", Highway Research Board Bulletin 158, Washington, D. C., 1957.

24. Granum, J. O., and C. H. Burnes, "Advance Programming Methods for State Highway Systems", Highway Research Board Bulletin 249, Washington, D. C., 1960.

25. Grunow, R. N., "Vehicle Delay at Signalized Intersections as a Factor in Determining Urban Priorities", Highway Research Board Bulletin 194, Washington, D. C., 1958.

26. Grunow, R. N., "PERT and Its Application to Highway Management", H.R.R. 32, Highway Research Board, Washington, D. C., 1963.

27. Hall, E. M., and C. O. Hixon, "The Use of a Priority Formula in Urban Street Programming", H.R.R. 87, Highway Research Board, Washington, D. C., 1965.

28. Hejal, S. S., "Traffic Speed Report No. 87", Unpublished Report, Joint Highway Research Project No. 32, Purdue University, Indiana, 1969.

29. Hejal, S. S., and H. L. Michael, "A Predictive Model for Travel Times on Two-Lane State Highways", Unpublished Report, Joint Highway Research Project No. 19, Purdue University, Indiana, 1970.

30. Hejal, S. S. and H. L.Michael, "The Estimated Direct Costs (1970) of Traffic Accidents on Indiana Rural State Highways", Unpublished Report, Joint Highway Research Project No. 20, Purdue University, Indiana, 1970.

31. Highway Capacity Manual, Highway Research Board, Special Report 87, Washington, D. C., 1965.

32. Hooper, C. J., "Consideration of Rating Urban Streets", Highway Research Board Bulletin 53, Washington, D. C., 1952.

33. Humphrey, H. A., and J. A. Foster, "What Should Highway Needs Reports Contain?", Highway Research Board Bulletin 194, Washington, D. C., 1958.

34. Johnston, J. E., "The Economic Cost of Traffic Accidents in Relation to Highway Planning and a Comparison of Accident Costs in Utah and Massachusetts", Public Roads, Vol. 31, No. 2, June 1960.

35. Jorgensen, R. E., "Use of Sufficiency Rating in Long Range Planning", Highway Research Board Bulletin 53, Washington, D. C., 1952.

36. Kipp, O. L., "Sufficiency Rating as an Administrative Tool", Highway Research Board Bulletin 53, Washington, D. C., 1952.

37. Kipp, O. L., and W. T. Lusky, "Appraisal of Needs and Cost Estimating Procedures", H.R.R. 87, Highway Research Board, Washington, D. C., 1965.

38. Koppelman, F. S., "A Model for Highway Needs Evaluation", H.R.R. 314, Highway Research Board, Washington, D. C., 1970.

39. Laing, J. J., "Estimating Maintenance Needs", Highway Research Board Bulletin 158, Washington, D. C., 1957.

40. Matleson, H. H., J. W. Hall, and R. B. Sawhill, "Accident Rates and Costs on Urban Arterials and Freeways", paper presented to Highway Research Board 49th Annual Meeting, 1970.

41. McMonagle, J. C., "A Comparative Method of Scientific Programming", Proceedings, 35th Annual Meeting, Highway Research Board, Washington, D. C., 1956.

42. Michael, H. L., "Highway Planning", Highway Engineering Handbook, Woods, K. B., Editor-in-Chief, McGraw-Hill Inc., New York, 1960.

43. Accident Facts, 1967, National Safety Council, Washington, D. C., 1968.

44. de Neufville, R., and Y. Mori, "Optimal Highway Staging by Dynamic Programming", Transportation Journal of ASCE, Vol. 96, No. TE1, February, 1970.

45. Ohio Department of Highways, Sufficiency Rating Procedure for Rural Two and Three Major Thoroughfare and Auxilliary Highway Systems in Ohio.

46. Oppenlander, J. C., "Multivariate Analysis of Vehicular Speeds", H.R.R. 35, Highway Research Board, Washington, D. C., 1963.

47. Oppenlander, J. C., "Variables Influencing Spot-Speed Characteristics", Highway Research Board, Special Report 89, Washington, D. C., 1966.

48. Reed, M. F., Jr., and R. E. Futrell, "Multiple Project Scheduling of Preconstruction Engineering Activities", H.R.R. 87, Highway Research Board, Washington, D. C., 1965.

49. Smith, R. N., and T. N. Tamburrie, "Direct Costs of California State Highway Accidents", H.R.R. 225, Highway Research Board, Washington, D. C., 1968.

50. Smith, W. E., "Various Optimizers for Single-State Production", Naval Research Logistic Quarterly 3, No. 1, March 1965.

51. Soberman, R. M., and G. A. Clark, "A General Purpose Model for Motor Vehicle Operating Costs", H.R.R. 314, Highway Research Board, Washington, D. C., 1970.

52. Staffled, P. R., "Possible Areas of Improvements in Rating Procedures", Highway Research Board Bulletin 53, Washington, D. C., 1952.

53. Swanson, J. A., "General Comments on Sufficiency Rating Procedures", Highway Research Board Bulletin 53, Washington, D. C., 1952.

54. Thomas, E. N., and J. L. Schoffer, "Strategies for the Evaluation of Alternative Transportation Plans", Highway Research Board, Special Report 96, Washington, D. C., 1970.

55. Twombly, B. B., "The Economic Cost of Traffic Accidents in Relation to the Highway Systems", Public Roads, Vol. 31, No. 2, June 1960.

56. Willey, W. E., "Arizona's Experience with Sufficiency Ratings", Highway Research Board Bulletin 53, Washington, D. C., 1952.

57. Winfrey, R., Economic Analysis for Highways, International Text Book Co., Scranton, Pennsylvania, 1969.

APPENDIX A

ROAD USER OPERATING COSTS TABLES

TABLE A1. ROAD USER OPERATING COSTS FOR PASSENGER VEHICLES ON RURAL TWO-LANE HIGHWAYS (DOLLARS PER 1000 VEHICLE-MILES)

			LEVEL OF SERVICE									
			A		B		C		D		E	
SPEED (MPH)	GRADE (PRCNT)	TIME COSTS	OPRATE	TOTAL	OPRATE	TOTAL	OPRATE	TOTAL	OPRATE	TOTAL	OPRATE	TOTAL
30	0	100.0	41.4	141.4	41.6	141.6	42.2	142.2	42.8	142.8	44.1	144.1
	1	100.0	41.0	141.0	41.2	141.2	41.8	141.8	42.3	142.3	43.6	143.6
	2	100.0	41.3	141.3	41.5	141.5	42.1	142.1	42.7	142.7	43.9	143.9
	3	100.0	41.7	141.7	42.0	142.0	42.6	142.6	43.2	143.2	44.5	144.5
	4	100.0	42.4	142.4	42.7	142.7	43.3	143.3	44.0	144.0	45.4	145.4
	5	100.0	43.6	143.6	43.9	143.9	44.7	144.7	45.4	145.4	46.9	146.9
	6	100.0	45.1	145.1	45.4	145.4	46.2	146.2	47.1	147.1	48.8	148.8
35	0	85.7	41.1	126.8	41.4	127.1	42.5	128.2	45.3	131.0		
	1	85.7	40.9	126.6	41.2	126.9	42.3	128.0	45.0	130.7		
	2	85.7	41.2	126.9	41.4	127.1	42.6	128.3	45.4	131.1		
	3	85.7	41.6	127.4	41.9	127.6	43.1	128.9	46.0	131.7		
	4	85.7	42.3	128.0	42.6	128.3	43.9	129.7	47.0	132.7		
	5	85.7	43.2	129.0	43.6	129.3	45.0	130.7	48.2	134.0		
	6	85.7	44.7	130.4	45.1	130.8	46.7	132.4	50.3	136.0		
40	0	75.0	41.0	116.0	41.6	116.6	44.7	119.7				
	1	75.0	41.0	116.0	41.6	116.6	44.7	119.7				
	2	75.0	41.2	116.2	41.9	116.9	45.0	120.0				
	3	75.0	41.6	116.6	42.3	117.3	45.5	120.5				
	4	75.0	42.2	117.2	43.0	118.0	46.4	121.4				
	5	75.0	43.0	118.0	43.8	118.8	47.4	122.4				
	6	75.0	44.4	119.4	45.3	120.3	49.3	124.3				
45	0	66.7	41.3	108.0	42.9	109.6	51.2	117.8				
	1	66.7	41.5	108.1	43.1	109.7	51.4	118.1				
	2	66.7	41.7	108.3	43.3	109.9	51.7	118.4				
	3	66.7	42.0	108.7	43.7	110.3	52.3	119.0				
	4	66.7	42.6	109.2	44.3	111.0	53.3	119.9				
	5	66.7	43.4	110.0	45.2	111.9	54.6	121.2				
	6	66.7	44.6	111.3	46.6	113.2	56.7	123.3				
50	0	60.0	42.1	102.1	45.7	105.7						
	1	60.0	42.3	102.3	45.9	105.9						
	2	60.0	42.4	102.4	46.1	106.1						
	3	60.0	42.7	102.7	46.5	106.5						
	4	60.0	43.2	103.2	47.1	107.1						
	5	60.0	44.0	104.0	48.0	108.0						
	6	60.0	45.1	105.1	49.3	109.3						
55	0	54.5	43.1	97.7	50.6	105.2						
	1	54.5	43.3	97.8	50.8	105.3						
	2	54.5	43.3	97.8	50.8	105.3						
	3	54.5	43.5	98.0	51.1	105.7						
	4	54.5	44.0	98.5	51.8	106.3						
	5	54.5	44.7	99.3	52.7	107.3						
	6	54.5	45.8	100.4	54.2	108.7						
60	0	50.0	44.9	94.9								
	1	50.0	44.8	94.8								
	2	50.0	44.8	94.8								
	3	50.0	45.0	95.0								
	4	50.0	45.4	95.4								
	5	50.0	46.2	96.2								
	6	50.0	47.3	97.3								
65	0	46.2	46.8	92.9								
	1	46.2	46.8	92.9								
	2	46.2	46.8	92.9								
	3	46.2	47.0	93.2								
	4	46.2	47.4	93.5								
	5	46.2	47.9	94.1								
	6	46.2	48.7	94.8								

FUEL COST	= $	.23 PER GALLON
OIL COST	= $	.75 PER QUART
DEPRECIABLE VALUE	= $	2800.00
LABOUR COST	= $	5.00 PER HOUR
TIRE COST	= $	25.00 PER TIRE (PLUS RETREADS)
TIME COST	= $	3.00 PER HOUR

TABLE A2. ROAD USER OPERATING COSTS FOR SINGLE UNIT TRUCKS ON RURAL TWO-LANE HIGHWAYS (DOLLARS PER 1000 VEHICLE-MILES)

			LEVEL OF SERVICE									
			A		B		C		D		E	
SPEED (MPH)	GRADE (PRCNT)	TIME COSTS	OPRATE	TOTAL	OPRATE	TOTAL	OPRATE	TOTAL	OPRATE	TOTAL	OPRATE	TOTAL
30	0	158.3	75.1	233.4	75.6	234.0	77.2	235.5	78.6	236.9	81.2	239.5
	1	158.3	75.0	233.3	75.5	233.9	77.1	235.4	78.5	236.8	81.1	239.4
	2	158.3	75.0	233.3	75.6	233.9	77.1	235.4	78.5	236.8	81.1	239.4
	3	158.3	75.9	234.3	76.5	234.9	78.2	236.5	79.6	238.0	82.3	240.7
	4	158.3	77.2	235.6	77.9	236.2	79.7	238.0	81.2	239.6	84.1	242.4
	5	158.3	79.2	237.6	80.0	238.3	82.0	240.3	83.7	242.1	86.9	245.2
	6	158.3	81.9	240.2	82.8	241.1	85.1	243.4	87.0	245.4	90.5	248.9
35	0	135.7	76.6	212.3	77.3	213.0	80.0	215.7	85.3	221.0		
	1	135.7	76.5	212.2	77.2	212.9	79.9	215.6	85.2	220.9		
	2	135.7	76.5	212.3	77.2	213.0	79.9	215.7	85.2	220.9		
	3	135.7	77.7	213.4	78.4	214.1	81.3	217.0	86.9	222.5		
	4	135.7	79.1	214.8	79.9	215.6	82.9	218.7	88.9	224.5		
	5	135.7	81.2	216.9	82.1	217.8	85.5	221.2	91.9	227.5		
	6	135.7	84.1	219.8	85.1	220.8	89.0	224.7	95.9	231.6		
40	0	118.8	79.0	197.8	80.5	199.2	86.7	205.5				
	1	118.8	78.9	197.7	80.4	199.2	86.6	205.4				
	2	118.8	79.0	197.8	80.5	199.3	86.7	205.5				
	3	118.8	80.3	199.1	81.9	200.6	88.4	207.1				
	4	118.8	82.0	200.7	83.6	202.4	90.6	209.3				
	5	118.8	84.2	203.0	86.1	204.8	93.7	212.4				
	6	118.8	87.4	206.2	89.5	208.2	98.0	216.7				
45	0	105.6	82.6	188.2	85.7	191.3	101.4	206.9				
	1	105.6	82.6	188.1	85.7	191.3	101.3	206.9				
	2	105.6	82.8	188.4	86.0	191.6	101.8	207.3				
	3	105.6	84.3	189.8	87.6	193.1	104.2	209.7				
	4	105.6	86.0	191.6	89.6	195.2	107.2	212.8				
	5	105.6	88.7	194.2	92.5	198.1	111.6	217.1				
50	0	95.0	86.9	181.9	93.7	188.7						
	1	95.0	86.7	181.7	93.6	188.6						
	2	95.0	87.3	182.3	94.2	189.2						
	3	95.0	88.9	183.9	96.3	191.3						
55	0	86.4	91.9	178.3	106.0	192.4						
	1	86.4	91.7	178.1	105.7	192.1						
	2	86.4	92.6	179.0	107.0	193.4						
60	0	79.2	98.2	177.4								
	1	79.2	97.9	177.1								

```
FUEL COST          = $      .22 PER GALLON
OIL COST           = $      .50 PER QUART
DEPRECIABLE VALUE  = $  3500.00
LABOUR COST        = $     5.00 PER HOUR
TIRE COST          = $   100.00 PER TIRE (PLUS RETREADS)
TIME COST          = $     4.75 PER HOUR
```

TABLE A3. ROAD USER OPERATING COSTS FOR COMBINATION TRUCKS ON RURAL TWO-LANE HIGHWAYS (DOLLARS PER 1000 VEHICLE-MILES)

			LEVEL OF SERVICE									
			A		B		C		D		E	
SPEED (MPH)	GRADE (PRCNT)	TIME COSTS	OPRATE	TOTAL	OPRATE	TOTAL	OPRATE	TOTAL	OPRATE	TOTAL	OPRATE	TOTAL
30	0	216.7	132.3	349.0	133.6	350.2	136.8	353.5	139.5	356.1	143.9	360.6
	1	216.7	131.5	348.1	132.7	349.4	136.0	352.6	138.6	355.2	142.9	359.6
	2	216.7	134.3	350.9	135.5	352.2	138.8	355.4	141.4	358.1	146.0	362.7
	3	216.7	144.0	360.7	145.3	362.0	148.7	365.4	151.7	368.4	157.2	373.9
35	0	185.7	134.1	319.8	135.6	321.4	140.8	326.5	149.0	334.7		
	1	185.7	135.2	320.9	136.7	322.4	141.9	327.6	150.3	336.0		
	2	185.7	139.8	325.5	141.3	327.0	146.7	332.4	156.0	341.7		
	3	185.7	151.3	337.0	152.9	338.6	159.0	344.7	170.6	356.3		
40	0	162.5	139.8	302.3	142.5	305.0	152.8	315.3				
	1	162.5	142.8	305.3	145.6	308.1	156.5	319.0				
	2	162.5	149.8	312.3	152.7	315.2	164.9	327.4				
45	0	144.4	145.1	289.5	150.2	294.7	173.5	318.0				
	1	144.4	150.9	295.4	156.6	301.1	183.5	327.9				
	2	144.4	160.9	305.3	167.6	312.0	200.4	344.8				
50	0	130.0	154.6	284.6	145.2	295.2						
	1	130.0	164.1	294.1	177.1	307.1						
55	0	118.2	169.1	287.2	191.3	309.5						

FUEL COST = $ .18 PER GALLON
OIL COST = $ .25 PER QUART
DEPRECIABLE VALUE = $ 19000.00
LABOUR COST = $ 5.00 PRR HOUR
TIRE COST = $ 250.00 PER TIRE (PLUS RETREADS)
TIME COST = $ 6.50 PER HOUR

TABLE A4. ROAD USER OPERATING COSTS FOR PASSENGER VEHICLES ON RURAL FOUR-LANE HIGHWAYS (DOLLARS PER 1000 VEHICLE-MILES)

			LEVEL OF SERVICE									
			A		B		C		D		E	
SPEED (MPH)	GRADE (PRCNT)	TIME COSTS	OPRATE	TOTAL	OPRATE	TOTAL	OPRATE	TOTAL	OPRATE	TOTAL	OPRATE	TOTAL
30	0	100.0	41.4	141.4	41.6	141.6	42.2	142.2	42.6	142.6	43.0	143.0
	1	100.0	41.0	141.0	41.2	141.2	41.8	141.8	42.1	142.1	42.6	142.6
	2	100.0	41.3	141.3	41.5	141.5	42.1	142.1	42.4	142.4	42.9	142.9
	3	100.0	41.7	141.7	42.0	142.0	42.6	142.6	43.0	143.0	43.5	143.5
	4	100.0	42.4	142.4	42.7	142.7	43.3	143.3	43.7	143.7	44.3	144.3
	5	100.0	43.6	143.6	43.9	143.9	44.7	144.7	45.1	145.1	45.7	145.7
	6	100.0	45.1	145.1	45.4	145.4	46.2	146.2	46.8	146.8	47.5	147.5
35	0	85.7	41.1	126.8	41.4	127.1	42.0	127.8	42.7	128.4		
	1	85.7	40.9	126.6	41.2	126.9	41.9	127.6	42.5	128.2		
	2	85.7	41.2	126.9	41.4	127.1	42.1	127.8	42.8	128.5		
	3	85.7	41.6	127.4	41.9	127.6	42.7	128.4	43.4	129.1		
	4	85.7	42.3	128.0	42.6	128.3	43.4	129.1	44.2	129.9		
	5	85.7	43.2	129.0	43.6	129.3	44.5	130.2	45.3	131.0		
	6	85.7	44.7	130.4	45.1	130.8	46.1	131.9	47.1	132.8		
40	0	75.0	41.0	116.0	41.3	116.3	42.2	117.2	43.6	118.6		
	1	75.0	41.0	116.0	41.3	116.3	42.2	117.2	43.6	118.6		
	2	75.0	41.2	116.2	41.5	116.5	42.5	117.5	43.8	118.8		
	3	75.0	41.6	116.6	42.0	117.0	42.9	117.9	44.4	119.4		
	4	75.0	42.2	117.2	42.6	117.6	43.7	118.7	45.2	120.2		
	5	75.0	43.0	118.0	43.4	118.4	44.6	119.6	46.3	121.3		
	6	75.0	44.4	119.4	44.9	119.9	46.3	121.3	48.1	123.1		
45	0	66.7	41.3	108.0	41.8	108.5	43.3	109.9				
	1	66.7	41.5	108.1	42.0	108.6	43.4	110.1				
	2	66.7	41.7	108.3	42.2	108.8	43.6	110.3				
	3	66.7	42.0	108.7	42.5	109.2	44.1	110.7				
	4	66.7	42.6	109.2	43.1	109.8	44.8	111.4				
	5	66.7	43.4	110.0	44.0	110.6	45.8	112.4				
	6	66.7	44.6	111.3	45.3	112.0	47.3	114.0				
50	0	60.0	42.1	102.1	43.1	103.1	46.1	106.1				
	1	60.0	42.3	102.3	43.2	103.2	46.3	106.3				
	2	60.0	42.4	102.4	43.4	103.4	46.4	106.4				
	3	60.0	42.7	102.7	43.7	103.7	46.9	106.9				
	4	60.0	43.2	103.2	44.3	104.3	47.6	107.6				
	5	60.0	44.0	104.0	45.1	105.1	48.7	108.7				
	6	60.0	45.1	105.1	46.3	106.3	50.2	110.2				
55	0	54.5	43.1	97.7	45.2	99.8						
	1	54.5	43.3	97.8	45.4	99.9						
	2	54.5	43.3	97.8	45.4	99.9						
	3	54.5	43.5	98.0	45.7	100.2						
	4	54.5	44.0	98.5	46.2	100.8						
	5	54.5	44.7	99.3	47.1	101.6						
	6	54.5	45.8	100.4	48.3	102.9						
60	0	50.0	44.9	94.9								
	1	50.0	44.8	94.8								
	2	50.0	44.8	94.8								
	3	50.0	45.0	95.0								
	4	50.0	45.4	95.4								
	5	50.0	46.2	96.2								
	6	50.0	47.3	97.3								
65	0	46.2	46.8	92.9								
	1	46.2	46.8	92.9								
	2	46.2	46.8	92.9								
	3	46.2	47.0	93.2								
	4	46.2	47.4	93.5								
	5	46.2	47.9	94.1								
	6	46.2	48.7	94.8								

FUEL COST = $ .23 PER GALLON
OIL COST = $ .75 PER QUART
DEPRECIABLE VALUE = $ 2800.00
LABOUR COST = $ 5.00 PER HOUR
TIRE COST = $ 25.00 PER TIRE (PLUS RETREADS)
TIME COST = $ 3.00 PER HOUR

TABLE A5. ROAD USER OPERATING COSTS FOR SINGLE UNIT TRUCKS ON RURAL FOUR-LANE HIGHWAYS (DOLLARS PER 1000 VEHICLE-MILES)

			LEVEL OF SERVICE									
			A		B		C		D		E	
SPEED (MPH)	GRADE (PRCNT)	TIME COSTS	OPRATE	TOTAL	OPRATE	TOTAL	OPRATE	TOTAL	OPRATE	TOTAL	OPRATE	TOTAL
30	0	158.3	75.1	233.4	75.6	234.0	77.2	235.5	78.2	236.5	79.3	237.7
	1	158.3	75.0	233.3	75.5	233.9	77.1	235.4	78.1	236.4	79.2	237.5
	2	158.3	75.0	233.3	75.6	233.9	77.1	235.4	78.1	236.4	79.3	237.6
	3	158.3	75.9	234.3	76.5	234.9	78.2	236.5	79.2	237.5	80.4	238.8
	4	158.3	77.2	235.6	77.9	236.2	79.7	238.0	80.8	239.1	82.1	240.4
	5	158.3	79.2	237.6	80.0	238.3	82.0	240.3	83.3	241.6	84.8	243.1
	6	158.3	81.9	240.2	82.8	241.1	85.1	243.4	86.5	244.9	88.2	246.5
35	0	135.7	76.6	212.3	77.3	213.0	79.2	214.9	80.8	216.5		
	1	135.7	76.5	212.2	77.2	212.9	79.1	214.8	80.7	216.4		
	2	135.7	76.5	212.3	77.2	213.0	79.1	214.8	80.7	216.4		
	3	135.7	77.7	213.4	78.4	214.1	80.4	216.1	82.1	217.8		
	4	135.7	79.1	214.8	79.9	215.6	82.0	217.8	83.8	219.5		
	5	135.7	81.2	216.9	82.1	217.8	84.5	220.2	86.5	222.2		
	6	135.7	84.1	219.8	85.1	220.8	87.9	223.6	90.2	225.9		
40	0	118.8	79.0	197.8	79.9	198.6	82.3	201.0	85.2	203.9		
	1	118.8	78.9	197.7	79.8	198.5	82.2	201.0	85.1	203.8		
	2	118.8	79.0	197.8	79.9	198.6	82.3	201.1	85.2	203.9		
	3	118.8	80.3	199.1	81.2	199.9	83.8	202.5	86.9	205.5		
	4	118.8	82.0	200.7	82.9	201.7	85.7	204.5	88.9	207.7		
	5	118.8	84.2	203.0	85.3	204.1	88.5	207.2	92.0	210.8		
	6	118.8	87.4	206.2	88.7	207.4	92.3	211.0	96.3	215.0		
45	0	105.6	82.6	188.2	83.8	189.4	87.3	192.8				
	1	105.6	82.6	188.1	83.8	189.3	87.3	192.8				
	2	105.6	82.8	188.4	84.0	189.6	87.5	193.1				
	3	105.6	84.3	189.8	85.5	191.1	89.2	194.8				
	4	105.6	86.0	191.6	87.4	193.0	91.4	197.0				
	5	105.6	88.7	194.2	90.2	195.7	94.6	200.2				
50	0	95.0	86.9	181.9	88.9	183.9	95.4	190.4				
	1	95.0	86.7	181.7	88.8	183.8	95.3	190.3				
	2	95.0	87.3	182.3	89.3	184.3	95.9	190.9				
	3	95.0	88.9	183.9	91.1	186.1	98.0	193.0				
55	0	86.4	91.9	178.3	96.2	182.6						
	1	86.4	91.7	178.1	96.0	182.4						
	2	86.4	92.6	179.0	96.9	183.3						
60	0	79.2	98.2	177.4								
	1	79.2	97.9	177.1								

```
FUEL COST           = $      .22 PER GALLON
OIL COST            = $      .50 PER QUART
DEPRECIABLE VALUE   = $  3500.00
LABOUR COST         = $     5.00 PER HOUR
TIRE COST           = $   100.00 PER TIRE (PLUS RETREADS)
TIME COST           = $     4.75 PER HOUR
```

TABLE A6. ROAD USER OPERATING COSTS FOR COMBINATION TRUCKS ON RURAL FOUR-LANE HIGHWAYS (DOLLARS PER 1000 VEHICLE-MILES)

			LEVEL OF SERVICE									
			A		B		C		D		E	
SPEED (MPH)	GRADE (PRCNT)	TIME COSTS	OPRATE	TOTAL	OPRATE	TOTAL	OPRATE	TOTAL	OPRATE	TOTAL	OPRATE	TOTAL
30	0	216.7	132.3	349.0	133.6	350.2	136.8	353.5	138.9	355.5	141.2	357.9
	1	216.7	131.5	348.1	132.7	349.4	136.0	352.6	138.0	354.7	140.3	357.0
	2	216.7	134.3	350.9	135.5	352.2	138.8	355.4	140.8	357.5	143.2	359.8
	3	216.7	144.0	360.7	145.3	362.0	148.7	365.4	150.9	367.6	153.5	370.1
35	0	185.7	134.1	319.8	135.6	321.4	139.7	325.4	142.9	328.5		
	1	185.7	135.2	320.9	136.7	322.4	140.8	326.5	143.9	329.6		
	2	185.7	139.8	325.5	141.3	327.0	145.3	331.0	148.5	334.2		
	3	185.7	151.3	337.0	152.9	338.6	157.2	342.9	160.7	346.4		
40	0	162.5	139.8	302.3	141.7	304.2	146.9	309.4	151.9	314.4		
	1	162.5	142.8	305.3	144.7	307.2	149.9	312.4	155.2	317.7		
	2	162.5	149.8	312.3	151.6	314.1	156.9	319.4	162.6	325.1		
45	0	144.4	145.1	289.5	147.6	292.0	154.7	299.2				
	1	144.4	150.9	295.4	153.5	297.9	160.8	305.3				
	2	144.4	160.9	305.3	163.5	308.0	171.3	315.7				
50	0	130.0	154.6	284.6	158.5	288.5	170.4	300.4				
	1	130.0	164.1	294.1	168.4	298.4	181.8	311.8				
55	0	118.2	169.1	287.2	176.7	294.8						

FUEL COST = $ .18 PER GALLON
OIL COST = $ .25 PER QUART
DEPRECTABLE VALUE = $ 19000.00
LABOUR COST = $ 5.00 PRR HOUR
TIRE COST = $ 250.00 PER TIRE (PLUS RETREADS)
TIME COST = $ 6.50 PER HOUR

APPENDIX B

COMPUTER PROGRAM FOR THE ECONOMIC PRIORITY MODEL APPLICATION

APPENDIX B

List of Computer Program Definitions

CPC2L: Passenger car operating cost matrix, two-lane highways.

CSU2L: Single unit truck operating cost matrix, two-lane highways.

CCT2L: Combination truck operating cost matrix, two-lane highways.

CPC4L: Passenger car operating cost matrix, four-lane highways.

CSU4L: Single unit truck operating cost matrix, four-lane highways.

CCT4L: Combination truck operating cost matrix, four-lane highways.

ROW1,ROW2, etc: Right of ways costs per mile.

BRD1, BRD2, etc: Bridge unit costs per mile.

CRF10,CRF18,etc: Capital recovery factors for six percent interest rate, 10 years, 18 years, etc. amortization period.

VT(I): Vector component I, two-lane construction model.

VF(I): Vector component I, four-lane construction model.

VM(I): Vector component I, maintenance model.

VR(I): Vector component I, reconstruction model.

VS(I): Vector component I, operating speed model.

BCR(I): Benefit-cost ratio for alternative plan I.

CAP(I): Total capital cost, plan I.

RUC(I): Road user cost for average design year, plan I.

ANCAP(I): Annual capital cost, plan I.

FLAG(I): Right of way requirements indicator.

ADTOO: Average daily traffic, initial.

ADT07: Average daily traffic after seven years.

ADT25: Average daily traffic at the end of design period (25 years).

DAV: Design annual volume.

DHV: Design hourly volume.

DACCS: Design accident cost for reconstructed sections.

DACC2: Design accident cost for two-lane ideal highways.

DACC4: Design accident cost for four-lane ideal highways.

P1: Percent of trucks in traffic stream.

P2: Fraction of combination trucks in truck stream.

VEL: Velocity of passenger vehicles.

LOS2: Level of service, two-lane highways subroutine.

LOS4: Level of service, four-lane highways subroutine.

SPEED2: Operating speed subroutine, two-lane highway.

SPEED4: Operating speed subroutine, four-lane highway.

USER2: Road user cost subroutine, two-lane highway.

USER4: Road user cost subroutine, four-lane highway.

CSM: Roadway maintenance costs model.

RCST: Roadway reconstruction cost model.

CSC2: Roadway construction model, two-lane highways.

CSC4: Roadway construction model, four-lane highways.

```
3178,MICHALL,CM60000,T90,L20000,C2000.
RUN(S)
CLEAR.
MAP(ON)
LGO.
7
      PROGRAM FINAL(INPUT,OUTPUT,PUNCH,TAPE1,TAPE5=INPUT,TAPE6=OUTPUT,
     1TAPE7=PUNCH)
      DIMENSION CPC2L(56,5),CSU2L(56,5),CCT2L(56,5),CPC4L(56,5)
      DIMENSION CSU4L(56,5),CCT4L(56,5),VS(7),VM(7),VR(7),VT(7),VF(7)
      DIMENSION BCR(7),CAP(7),ANCAP(7),RUC(7),FLAG(7)
      DATA A1,B1,C1,D1/ 8H NEW ROW,8H   SAME ,8HADD. ROW,8H         /
      REAL LENGTH,MAXBCR
      INTEGER GRADE
  100 FORMAT(5(2X,F5.2))
  200 FORMAT(F1.0,F4.0,2F2.0,F3.0,2X,F4.2,2X,2F1.0,2F3.0, 2F2.0,3X,
     12F2.0,8X,F3.0,2F3.0,F4.0,F2.0,4X,F4.0)
  300 FORMAT(2X/50X,* ANNUAL ROAD-USER COST *,5(F7.1,1X)/50X,* ANNUAL  C
     1APITAL  COST *,5(F7.1,1X)
     2/4X,F2.0,4X,F4.0,6X,F2.0,6X,F2.0,6X,F3.0,4X,F5.2,2X,
     3* BENEFIT  COST  RATIO  *,5(F7.1,1X)/50X,* TOTAL  CAPITAL  COST  *
     4,5(F7.1,1X)/50X,* RIGHT OF WAY  NEED    *,5A8)
  400 FORMAT(1H1, * DIST.  HIGHWAY  COUNTY  CONTROL    SECTION      *,
     123X,*  PLAN 0  PLAN 1  PLAN 2  PLAN 3  PLAN 4 *,
     22X/*         NUMBER   NUMBER  SECTION  NUMBER LENGTH  *)
  500 FORMAT(F1.0,F4.0,2F2.0,F3.0,2X,F5.2,4X,I1,2X,A8,F7.1,F6.2)
C
C    INPUT DATA
C
      READ(5,100) ((CPC2L(I,J),J=1,5),I=1,56)
      READ(5,100) ((CSU2L(I,J),J=1,5),I=1,56)
      READ(5,100) ((CCT2L(I,J),J=1,5),I=1,56)
      READ(5,100) ((CPC4L(I,J),J=1,5),I=1,56)
      READ(5,100) ((CSU4L(I,J),J=1,5),I=1,56)
      READ(5,100) ((CCT4L(I,J),J=1,5),I=1,56)
      ROW1=52.3
      ROW2=36.9
      ROW3=145.7
      ROW4=125.8
      BRD1=60.
      BRD2=40.
      BRD3=80.
      BRD4=80.
C    6 PERCENT INTREST CAPITAL RECOVERY FACTORS
      CRF10=.1359
      CRF18=.0924
      CRF35=.0690
      CRF50=.0634
      CRF60=.0619
C
C   RESET ARRAYS FOR NEW SECTION
C
   11 LINE=0
      WRITE(6,400)
    1 DO 2 I=1,6
      VT(I)=0.0
      VF(I)=0.0
      VM(I)=0.0
      VR(I)=0.0
      VS(I)=0.0
      BCR(I)=0.0
```

```
      CAP(I)=0.0
      RUC(I)=0.0
      ANCAP(I)=0.0
      FLAG(I)=CI
    2 CONTINUE
      READ(5,200) DIST,HWYNO,COUNTY,CONTRL,SUBSEC,LENGTH,ACCESS,TERR,
     1ADT00,PHV,GROWTH,TRUCK,W1,W2,ROW,SSD,ALIGNE,RPSD,SURF,ACCDNT
      IF(EOF,5) 6000,6
    6 WIDTH=W1+W2
      IF(WIDTH.GT.24.)  WIDTH=24.
      ADT00=ADT00*100.
      ADT07=ADT00*((1.+GROWTH/1000.)**7)
      ADT25=ADT00*((1.+GROWTH/1000.)**25)
      DAV=(ADT00+ADT25)*365./2.0
      DHV=PHV*0.563*(ADT00+ADT25)/(ADT00*2.0)
      VS(1)=DHV
      VS(2)=0.0
      DACCS=(0.570*LENGTH*DAV)/100000.
      DACC2=(0.510*LENGTH*DAV)/100000.
      DACC4=(0.445*LENGTH*DAV)/100000.
      EACCS=ACCDNT*0.5*2.86*(ADT00+ADT25)/(ADT00*2.0)
      IF(EACCS.LT.DACCS) EACCS=DACCS
      P1=TRUCK*0.01
      P2=0.4
      GRADE=(TERR-1.0)*2.0
C
C    CALCULATE EXISTING CONDITIONS ANNUAL COST
C
      VS(3)=WIDTH
      VS(4)=SSD
      VS(5)=ALIGNE
      VS(6)=RPSD
      CALL SPEED2(VEL,VS)
      EVEL=VEL+0.0113*DHV
      CALL LOS2(LOS,DHV,VEL,P1,TERR)
      CALL USER2(RUCST,VEL,LOS,P1,P2,GRADE,CPC2L,CSU2L,CCT2L)
      RUC(1)=(RUCST*LENGTH*DAV)/10.**6+EACCS
      FLAG(1)=BI
C
C    MAINTENANCE  REQUIREMENTS
C
      IF(SURF.LT.4.) GO TO 1000
      IF(ADT00.GT.1500.) VM(1)=1.7
      IF(ADT00.LE.1500.) VM(2)=1.4
      IF(ALIGNE.GT.10.) VM(3)=1.0
      IF(SURF.GT.5.) VM(4)=1.0
      VM(5)=WIDTH
      CSM=-8.65+5.90*VM(1)+5.02*VM(2)+3.61*VM(3)+5.56*VM(4)+.471*VM(5)
      CAP(1)=CSM*LENGTH
      ANCAP(1)=CSM*CRF10*LENGTH
C
C   RECONSTRUCTION  REQUIREMENTS
C
 1000 VS(3)=24.
      IF(ROW.GE.60..AND.TERR.LE.1.) GO TO 1001
      IF(ROW.GE.80..AND.TERR.LE.2.) GO TO 1001
      IF(ROW.GE.100..AND.TERR.LE.3.) GO TO 1001
      GO TO 3
 1001 IF(SURF.GE.5.) VR(1)=1.0
      IF(ALIGNE.GT.10..OR.SSD.GT.8.) VR(2)=1.0
      VR(3)=3.0
```

```
      VR(4)=24.-WIDTH
      VR(5)=3C.
      RCST=2.82+6.02*VR(1)+15.13*VR(2)+4.11*VR(3)+2.27*VR(4)+C.36*VR(5)
      CAP(2)=(RCST+0.C)*LENGTH
      ANCAP(2)=RCST*CFF18*LENGTH
      IF(SSD.GT.8.) VS(4)=8.
      IF(ALIGNE.GT.20.) VS(5)=2C.
      CALL SPEEC2(VEL,VS)
      CALL LCS2(LCS,DHV,VEL,P1,TERR)
      CALL USER2(RUCST,VEL,LCS,F1,F2,GRADE,CPC2L,CSU2L,CC12L)
      RUC(2)=(RUCST*LENGTH*DAV)/10.**6+DACCS
      BCR(2)=(RUC(1)-RUC(2))/(ANCAP(2)-ANCAP(1))
      FLAG(2)=BI
    3 IF(ADT25.GT.700C.) GC TC 4
C
C   NEW 2-LANES CONSTRUCTION REQUIREMENTS
C
      VS(4)=0.0
      VS(5)=0.0
      VS(6)=VS(6)/3.0
      IF(RCW.GE.100.) GC TC 2001
      IF(RCW.GE.70.) GC TC 2002
C     NEW RCW ,150 FT
      VT(1)=1.0
      VT(3)=TERR-1.0
      CSC2=185.8*VT(1)+109.7*VT(2)+83.7*VT(3)+53.6*VT(4)
      CAP(3)=(CSC2+RCW1+BRC1)*LENGTH
      ANCAP(3)=(CSC2*CRF35+RCW1*CRF60+BRC1*CRF50)*LENGTH
      FLAG(3)=AI
      GC TC 21CO
C     REBUILDING EXISTING RCADWAY
 2CC1 VT(2)=1.C
      VT(3)=TERR-1.0
      CSC2=185.8*VT(1)+109.7*VT(2)+83.7*VT(3)+53.6*VT(4)
      CAP(3)=CSC2*LENGTH
      ANCAP(3)=CSC2*CFF35*LENGTH
      FLAG(3)=BI
      GC TC 2100
C     REBUILDING EXISTING RCADWY,ADDITIONAL RCW
 2CC2 VT(2)=1.C
      VT(3)=TERR-1.0
      CSC2=185.8*VT(1)+109.7*VT(2)+83.7*VT(3)+53.6*VT(4)
      CAP(3)=(CSC2+RCW2+BRC2)*LENGTH
      ANCAP(3)=(CSC2*CRF35+RCW2*CRF60+BRC2*CRF50)*LENGTH
      FLAG(3)=CI
 21CC CALL SPEEC2(VEL,VS)
      CALL LCS2(LCS,DHV,VEL,P1,TERR)
      CALL USER2(RUCST,VEL,LCS,F1,F2,GRADE,CPC2L,CSU2L,CC12L)
      RUC(3)=(RUCST*LENGTH*DAV)/10.**6+DACC2
      BCR(3)=(RUC(1)-RUC(3))/(ANCAP(3)-ANCAP(1))
      GC TC 5CCO
    4 IF(ADT07.GT.700C.) GC TC 4000
C
C   2-LANES WITH RCW FOR ADDITIONAL RCADWAY
C
      VS(4)=0.C
      VS(5)=0.0
      VS(6)=VS(6)/3.0
 3CCC IF(RCW.GE.2CO.) GC TC 3001
      IF(RCW.GE.100.) GC TC 3002
C     NEW RCW ,250 FT
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      VT(1)=1.0
      VT(3)=TERR-1.0
      CSC2=185.8*VT(1)+109.7*VT(2)+83.7*VT(3)+53.6*VT(4)
      CAP(4)=(CSC2+ROW3+BRD1)*LENGTH
      ANCAP(4)=(CSC2*CRF35+ROW3*CRF60+BRD1*CRF50)*LENGTH
      FLAG(4)=AI
      GO TO 3100
C     REBUILDING EXISTING ROADWAY
 3001 VT(2)=1.0
      VT(3)=TERR-1.0
      IF(RPSD.GT.20.) VT(4)=1.0
      CSC2=185.8*VT(1)+109.7*VT(2)+83.7*VT(3)+53.6*VT(4)
      CAP(4)=CSC2*LENGTH
      ANCAP(4)=CSC2*CRF35*LENGTH
      FLAG(4)=BI
      GO TO 3100
C     ADDITIONAL ROW REBUILDING EXISTING ROADWAY
 3002 IF(EVEL.GT.55..AND.WIDTH .GE.22.) GO TO 3003
      VT(2)=1.0
      IF(RPSD.GT.20.) VT(4)=1.0
      VT(3)=TERR-1.0
      CSC2=185.8*VT(1)+109.7*VT(2)+83.7*VT(3)+53.6*VT(4)
      CAP(4)=(CSC2+ROW4+BRD2)*LENGTH
      ANCAP(4)=(CSC2*CRF35+ROW4*CRF60+BRD1*CRF50)*LENGTH
      FLAG(4)=CI
      GO TO 3100
 3003 CAP(4)=ROW4*LENGTH
      ANCAP(4)=ROW4*CRF60*LENGTH
      FLAG(4)=CI
 3100 CALL SPEED2(VEL,VS)
      CALL LOS2(LOS,DHV,VEL,F1,TERR)
      CALL USER2(RUCST,VEL,LOS,F1,F2,GRADE,CPC2L,CSC2L,CC12L)
      RUC(4)=(RUCST*LENGTH*DAV)/10.**6+DACC2
      BCR(4)=(RUC(1)-RUC(4))/(ANCAP(4)-ANCAP(1))
      GO TO 5000
C
C  NEW 4-LANE CONSTRUCTION REQUIREMENTS
C
 4000 IF(ROW.GE.200.) GO TO 4001
      IF(ROW.GE.100.) GO TO 4002
C     NEW ROW,250 FT
      VF(2)=1.0
      VF(5)=TERR-1.0
      CSC4=217.0*VF(1)+300.4*VF(2)+178.8*VF(3)+52.5*VF(4)+153.2*VF(5)+
     1155.5*VF(6)
      CAP(5)=(CSC4+ROW3+BRD3)*LENGTH
      ANCAP(5)=(CSC4*CRF35+ROW3*CRF60+BRD3*CRF50)*LENGTH
      FLAG(5)=AI
      GO TO 4100
C     2 ADDITIONAL LANES
 4001 VF(3)=1.0
      IF(EVEL.LT.55..OR.WIDTH.LT.22.) VF(4)=1.0
      VF(5)=TERR-1.0
      CSC4=217.0*VF(1)+300.4*VF(2)+178.8*VF(3)+52.5*VF(4)+153.2*VF(5)+
     1155.5*VF(6)
      CAP(5)=(CSC4+BRD2)*LENGTH
      ANCAP(5)=(CSC4*CRF35+BRD2*CRF50)*LENGTH
      FLAG(5)=BI
      GO TO 4100
C     ADDITIONAL ROW ,NEW ROADWAY
 4002 VF(1)=1.0
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      VF(5)=TERR-1.0
      CSC4=217.0*VF(1)+300.4*VF(2)+178.8*VF(3)+52.5*VF(4)+153.2*VF(5)+
     1155.5*VF(6)
      CAP(5)=(CSC4+RCW4+BRC4)*LENGTH
      ANCAP(5)=(CSC4*CRF35+RCW4*CRF60+BRC4*CRF50)*LENGTH
      FLAG(5)=CI
 4100 CALL SPEED4(VEL,VS)
      CALL LCS4(LCS,DHV,VEL,F1,TERR)
      CALL USER4(RUCST,VEL,LCS,F1,F2,GRADE,CPC4L,CSU4L,CCT4L)
      RUC(5)=(RUCST*LENGTH*DAV)/10.**6+CAC(4
      BCR(5)=(RUC(1)-RUC(5))/(ANCAP(5)-ANCAP(1))
 5000 WRITE(6,300) (RUC(I),I=1,5),(ANCAP(I),I=1,5),DIST,HWYNC,COUNTY,CON
     1TRL,SUBSEC,LENGTH,(BCR(I),I=1,5),(CAP(I),I=1,5),(FLAG(I),I=1,5)
      MAXBCR=AMAX1(BCR(2),BCR(3),BCR(4),BCR(5))
      IF(MAXBCR.EQ.0.0) GO TO 5101
      DO 5100 IT=2,5
      IF(MAXBCR.EQ.BCR(IT)) GO TO 5102
 5100 CONTINUE
 5101 IT=1
 5102 WRITE(7,500) DIST,HWYNC,COUNTY,CONTRL,SUBSEC,LENGTH,IT,FLAG(IT),
     1CAP(IT),MAXBCR
      LINE=LINE+6
      IF(LINE.GE.54) GO TO 11
      GO TO 1
 6000 REWIND 1
      STOP
      END
      SUBROUTINE SPEED2(VEL,VS)
      DIMENSION VS(7)
      VEL=38.43-.0113*VS(1)-7.014*VS(2)+1.045*VS(3)-.308*VS(4)-.105*VS(5
     1)-.107*VS(6)
      IF(VEL.GT.65.) VEL=65.
      RETURN
      END
      SUBROUTINE SPEED4(VEL,VS)
      DIMENSION VS(7)
      VEL=67.7-(25./3000.)*VS(1)
      IF(VEL.GT.65.) VEL=65.
      RETURN
      END
      SUBROUTINE LCS2(LCS,DHV,VEL,F1,TERR)
      VCL=DHV+2.5*DHV*F1*TERR
      LCS=5
      IF(VEL.GE.35..AND.VCL.LE.1600.) LCS=4
      IF(VEL.GE.40..AND.VCL.LE.1300.) LCS=3
      IF(VEL.GE.50..AND.VCL.LE. 800.) LCS=2
      IF(VEL.GE.60..AND.VCL.LE. 400.) LCS=1
      RETURN
      END
      SUBROUTINE LCS4(LCS,DHV,VEL,F1,TERR)
      VCL=DHV+2.0*DHV*F1*TERR
      LCS=5
      IF(VEL.GE.35..AND.VCL.LE.3500.) LCS=4
      IF(VEL.GE.45..AND.VCL.LE.3000.) LCS=3
      IF(VEL.GE.55..AND.VCL.LE.2000.) LCS=2
      IF(VEL.GE.60..AND.VCL.LE.1200.) LCS=1
      RETURN
      END
      SUBROUTINE USER2(RUCST,VEL,LCS,F1,F2,GRADE,CPC2L,CSU2L,CCT2L)
      DIMENSION CPC2L(56,5),CSU2L(56,5),CCT2L(56,5)
      INTEGER GRADE
```

```
      I=GRADE+1
      V1=VEL
      V2=VEL-4.2
      V3=VEL-8.7
      IF(V1.LT.30.) V1=30.
      IF(V2.LT.30.) V2=30.
      IF(V3.LT.30.) V3=30.
    1 AV=(V1-30.)/5.
      K=AV
      AK=K
      DEL=AV-AK
      KK=I+7*K
      IF(CPC2L(KK+7,LCS).LT.0.1)  GO TO 10
      RL1=CPC2L(KK,LCS)+DEL*(CPC2L(KK+7,LCS)-CPC2L(KK,LCS))
      GO TO 2
   10 DO 11 J=1,7
      KR=I+7*(K+1-J)
   12 IF(CPC2L(KR,LCS).GT.0.1)  GO TO 13
      IF(KR.LT.8) KR=KR-1
      IF(KR.LT.8) GO TO 12
      GO TO 11
   13 RL1=CPC2L(KR,LCS)
      GO TO 2
   11 CONTINUE
    2 AV=(V2-30.)/5.
      K=AV
      AK=K
      DEL=AV-AK
      KK=I+7*K
      IF(CSU2L(KK+7,LCS).LT.0.1)  GO TO 20
      RL2=CSU2L(KK,LCS)+DEL*(CSU2L(KK+7,LCS)-CSU2L(KK,LCS))
      GO TO 3
   20 DO 21 J=1,7
      KR=I+7*(K+1-J)
   22 IF(CSU2L(KR,LCS).GT.0.1)  GO TO 23
      IF(KR.LT.8) KR=KR-1
      IF(KR.LT.8) GO TO 22
      GO TO 21
   23 RL2=CSU2L(KR,LCS)
      GO TO 3
   21 CONTINUE
    3 AV=(V3-30.)/5.
      K=AV
      AK=K
      DEL=AV-AK
      KK=I+7*K
      IF(CCT2L(KK+7,LCS).LT.0.1)  GO TO 30
      RL3=CCT2L(KK,LCS)+DEL*(CCT2L(KK+7,LCS)-CCT2L(KK,LCS))
      GO TO 4
   30 DO 31 J=1,7
      KR=I+7*(K+1-J)
   32 IF(CCT2L(KR,LCS).GT.0.1)  GO TO 33
      IF(KR.LT.8) KR=KR-1
      IF(KR.LT.8) GO TO 32
      GO TO 31
   33 RL3=CCT2L(KR,LCS)
      GO TO 4
   31 CONTINUE
    4 RLCST=RL1*(1.-P1)+RL2*P1*(1.-P2)+RL3*P1*P2
      RETURN
      END
```

```
      SUBROUTINE LSER4(RUCST,VEL,LCS,F1,F2,GRADE,CPC4L,CSU4L,CCT4L)
      DIMENSION CPC4L(56,5),CSU4L(56,5),CCT4L(56,5)
      INTEGER GRADE
      I=GRADE+1
      V1=VEL
      V2=VEL-3.7
      V3=VEL-9.7
      IF(V1.LT.30.) V1=30.
      IF(V2.LT.30.) V2=30.
      IF(V3.LT.30.) V3=30.
    1 AV=(V1-30.)/5.
      K=AV
      AK=K
      DEL=AV-AK
      KK=I+7*K
      IF(CPC4L(KK+7,LCS).LT.0.1)  GO TO 10
      RL1=CPC4L(KK,LCS)+DEL*(CPC4L(KK+7,LCS)-CPC4L(KK,LCS))
      GO TO 2
   10 DO 11 J=1,7
      KR=I+7*(K+1-J)
   12 IF(CPC4L(KR,LCS).GT.0.1)  GO TO 13
      IF(KR.LT.8) KR=KR-1
      IF(KR.LT.8) GO TO 12
      GO TO 11
   13 RL1=CPC4L(KR,LCS)
      GO TO 2
   11 CONTINUE
    2 AV=(V2-30.)/5.
      K=AV
      AK=K
      DEL=AV-AK
      KK=I+7*K
      IF(CSU4L(KK+7,LCS).LT.0.1)  GO TO 20
      RL2=CSU4L(KK,LCS)+DEL*(CSU4L(KK+7,LCS)-CSU4L(KK,LCS))
      GO TO 3
   20 DO 21 J=1,7
      KR=I+7*(K+1-J)
   22 IF(CSU4L(KR,LCS).GT.0.1)  GO TO 23
      IF(KR.LT.8) KR=KR-1
      IF(KR.LT.8) GO TO 22
      GO TO 21
   23 RL2=CSU4L(KR,LCS)
      GO TO 3
   21 CONTINUE
    3 AV=(V3-30.)/5.
      K=AV
      AK=K
      DEL=AV-AK
      KK=I+7*K
      IF(CCT4L(KK+7,LCS).LT.0.1)  GO TO 30
      RL3=CCT4L(KK,LCS)+DEL*(CCT4L(KK+7,LCS)-CCT4L(KK,LCS))
      GO TO 4
   30 DO 31 J=1,7
      KR=I+7*(K+1-J)
   32 IF(CCT4L(KR,LCS).GT.0.1)  GO TO 33
      IF(KR.LT.8) KR=KR-1
      IF(KR.LT.8) GO TO 32
      GO TO 31
   33 RL3=CCT4L(KR,LCS)
      GO TO 4
   31 CONTINUE
```

```
    4 RLCST=RL1*(1.-F1)+RU2*F1*(1.-F2)+RU3*P1*P2
      RETURN
      END
```

7

141.4	141.6	142.2	142.8	144.1
141.0	141.2	141.8	142.3	143.6
141.3	141.5	142.1	142.7	143.9
141.7	142.0	142.6	143.2	144.5
142.4	142.7	143.3	144.0	145.4
143.6	143.9	144.7	145.4	146.9
145.1	145.4	146.2	147.1	148.8
126.8	127.1	128.2	131.0	0.0
126.6	126.9	128.0	130.7	0.0
126.9	127.1	128.3	131.1	0.0
127.4	127.6	128.9	131.7	0.0
128.0	128.3	129.7	132.7	0.0
129.0	129.3	130.7	134.0	0.0
130.4	130.8	132.4	136.0	0.0
116.0	116.6	119.7	0.0	0.0
116.0	116.6	119.7	0.0	0.0
116.2	116.9	120.0	0.0	0.0
116.6	117.3	120.5	0.0	0.0
117.2	118.0	121.4	0.0	0.0
118.0	118.8	122.4	0.0	0.0
119.4	120.3	124.3	0.0	0.0
108.0	109.6	117.8	0.0	0.0
108.1	109.7	118.1	0.0	0.0
108.3	109.9	118.4	0.0	0.0
108.7	110.3	119.0	0.0	0.0
109.2	111.0	119.9	0.0	0.0
110.0	111.9	121.2	0.0	0.0
111.3	113.2	123.3	0.0	0.0
102.1	105.7	0.0	0.0	0.0
102.3	105.9	0.0	0.0	0.0
102.4	106.1	0.0	0.0	0.0
102.7	106.5	0.0	0.0	0.0
103.2	107.1	0.0	0.0	0.0
104.0	108.0	0.0	0.0	0.0
105.1	109.3	0.0	0.0	0.0
97.7	105.2	0.0	0.0	0.0
97.8	105.3	0.0	0.0	0.0
97.8	105.3	0.0	0.0	0.0
98.0	105.7	0.0	0.0	0.0
98.5	106.3	0.0	0.0	0.0
99.3	107.3	0.0	0.0	0.0
100.4	108.7	0.0	0.0	0.0
94.9	0.0	0.0	0.0	0.0
94.8	0.0	0.0	0.0	0.0
94.8	0.0	0.0	0.0	0.0
95.0	0.0	0.0	0.0	0.0
95.4	0.0	0.0	0.0	0.0
96.2	0.0	0.0	0.0	0.0
97.3	0.0	0.0	0.0	0.0
92.9	0.0	0.0	0.0	0.0
92.9	0.0	0.0	0.0	0.0
92.9	0.0	0.0	0.0	0.0
93.2	0.0	0.0	0.0	0.0
93.5	0.0	0.0	0.0	0.0
94.1	0.0	0.0	0.0	0.0
94.8	0.0	0.0	0.0	0.0
233.4	234.0	235.5	236.9	239.5

233.3	233.9	235.4	236.8	239.4
233.3	233.9	235.4	236.8	239.4
234.3	234.9	236.5	238.0	240.7
235.6	236.2	238.0	239.6	242.4
237.6	238.3	240.3	242.1	245.2
240.2	241.1	243.4	245.4	248.9
212.3	213.0	215.7	221.0	0.0
212.2	212.9	215.6	220.9	0.0
212.3	213.0	215.7	220.9	0.0
213.4	214.1	217.0	222.5	0.0
214.8	215.6	218.7	224.5	0.0
216.9	217.8	221.2	227.5	0.0
219.8	220.8	224.7	231.6	0.0
197.8	199.2	205.5	0.0	0.0
197.7	199.2	205.4	0.0	0.0
197.8	199.3	205.5	0.0	0.0
199.1	200.6	207.1	0.0	0.0
200.7	202.4	209.3	0.0	0.0
203.0	204.8	212.4	0.0	0.0
206.2	208.2	216.7	0.0	0.0
188.2	191.3	206.9	0.0	0.0
188.1	191.3	206.9	0.0	0.0
188.4	191.6	207.3	0.0	0.0
189.8	193.1	209.7	0.0	0.0
191.6	195.2	212.8	0.0	0.0
194.2	198.1	217.1	0.0	0.0
0.0	0.0	0.0	0.0	0.0
181.9	188.7	0.0	0.0	0.0
181.7	188.6	0.0	0.0	0.0
182.3	189.2	0.0	0.0	0.0
183.9	191.3	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
178.3	192.4	0.0	0.0	0.0
178.1	192.1	0.0	0.0	0.0
179.0	193.4	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
177.4	0.0	0.0	0.0	0.0
177.1	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
349.0	350.2	353.5	356.1	360.6
348.1	349.4	352.6	355.2	359.6
350.9	352.2	355.4	358.1	362.7
360.7	362.0	365.4	368.4	373.9
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0

C.C	0.C	0.0	0.0	0.C
319.8	321.4	326.5	334.7	0.C
32C.9	322.4	327.6	336.C	0.0
325.5	327.0	332.4	341.7	0.0
337.C	338.6	344.7	356.3	0.C
C.C	0.C	0.0	0.0	0.C
C.C	0.C	0.0	0.C	0.C
C.C	0.C	0.0	0.0	0.0
3C2.3	305.C	315.3	0.0	0.C
3C5.3	308.1	319.0	0.0	0.C
312.3	315.2	327.4	0.0	0.C
C.C	0.C	0.0	0.0	0.C
C.C	0.C	0.0	0.0	0.C
C.C	0.C	0.0	0.0	0.C
C.C	0.C	0.0	0.0	0.0
289.5	294.7	318.0	0.0	0.0
295.4	301.1	327.9	0.0	0.C
3C5.3	312.C	344.8	0.0	0.0
C.C	0.C	0.0	0.0	0.0
C.C	0.C	0.0	0.0	0.0
C.C	0.C	0.0	0.C	0.0
C.C	0.C	0.0	0.C	0.C
284.6	295.2	0.0	0.C	0.C
294.1	307.1	0.0	0.0	0.0
C.C	0.C	0.0	0.0	0.0
C.C	0.C	0.0	0.0	0.C
C.C	0.C	0.0	0.0	0.0
C.C	0.C	0.0	0.0	0.0
C.C	0.C	0.0	0.0	0.C
287.2	309.5	0.0	0.0	0.C
C.C	0.C	0.0	0.C	0.0
C.C	0.0	0.0	0.0	0.C
C.C	0.C	0.0	0.0	0.C
0.C	0.C	0.0	0.0	0.C
C.C	0.C	0.0	0.0	0.0
C.C	0.C	0.0	0.0	0.0
C.C	0.C	0.0	0.0	0.C
C.C	0.C	0.0	0.0	0.C
C.C	0.C	0.0	0.0	0.0
C.C	0.C	0.0	0.0	0.0
0.C	0.C	0.0	0.0	0.C
0.C	0.0	0.0	0.0	0.C
0.C	0.C	0.0	0.0	0.0
0.C	0.0	0.0	0.0	0.0
C.C	0.C	0.0	0.0	0.0
C.C	0.C	0.0	0.0	0.C
C.C	0.C	0.0	0.0	0.0
C.C	0.0	0.0	0.0	0.0
C.C	0.C	0.0	0.0	0.0
0.C	0.C	0.0	0.0	0.C
141.4	141.6	142.2	142.6	143.0
141.C	141.2	141.8	142.1	142.6
141.3	141.5	142.1	142.4	142.9
141.7	142.0	142.6	143.0	143.5
142.4	142.7	143.3	143.7	144.3
143.6	143.9	144.7	145.1	145.7
145.1	145.4	146.2	146.8	147.5
126.8	127.1	127.8	128.4	0.0
126.6	126.9	127.6	128.2	0.0
127.4	127.6	128.4	129.1	0.0
128.C	128.3	129.1	129.9	0.0

129.0	129.3	130.2	131.0	0.0
130.4	130.8	131.9	132.8	0.0
116.0	116.3	117.2	118.6	0.0
116.0	116.3	117.2	118.6	0.0
116.2	116.5	117.5	118.8	0.0
116.6	117.0	117.9	119.4	0.0
117.2	117.6	118.7	120.2	0.0
118.0	118.4	119.6	121.3	0.0
119.4	119.9	121.3	123.1	0.0
108.0	108.5	109.9	0.0	0.0
108.1	108.6	110.1	0.0	0.0
108.3	108.8	110.3	0.0	0.0
108.7	109.2	110.7	0.0	0.0
109.2	109.8	111.4	0.0	0.0
126.9	127.1	127.8	128.5	0.0
110.0	110.6	112.4	0.0	0.0
111.3	112.0	114.0	0.0	0.0
102.1	103.1	106.1	0.0	0.0
102.3	103.2	106.3	0.0	0.0
102.4	103.4	106.4	0.0	0.0
102.7	103.7	106.9	0.0	0.0
103.2	104.3	107.6	0.0	0.0
104.0	105.1	108.7	0.0	0.0
105.1	106.3	110.2	0.0	0.0
97.7	99.8	0.0	0.0	0.0
97.8	99.9	0.0	0.0	0.0
97.8	99.9	0.0	0.0	0.0
98.0	100.2	0.0	0.0	0.0
98.5	100.8	0.0	0.0	0.0
99.3	101.6	0.0	0.0	0.0
100.4	102.9	0.0	0.0	0.0
94.9	0.0	0.0	0.0	0.0
94.8	0.0	0.0	0.0	0.0
94.8	0.0	0.0	0.0	0.0
95.0	0.0	0.0	0.0	0.0
95.4	0.0	0.0	0.0	0.0
96.2	0.0	0.0	0.0	0.0
97.3	0.0	0.0	0.0	0.0
92.9	0.0	0.0	0.0	0.0
92.9	0.0	0.0	0.0	0.0
92.9	0.0	0.0	0.0	0.0
93.2	0.0	0.0	0.0	0.0
93.5	0.0	0.0	0.0	0.0
94.1	0.0	0.0	0.0	0.0
94.8	0.0	0.0	0.0	0.0
233.4	234.0	235.5	236.5	237.7
233.3	233.9	235.4	236.4	237.6
233.3	233.9	235.4	236.4	237.6
234.3	234.9	236.5	237.5	238.8
235.6	236.2	238.0	239.1	240.4
237.6	238.3	240.3	241.6	243.1
240.2	241.1	243.4	244.9	246.6
212.3	213.0	214.9	216.5	0.0
212.2	212.9	214.8	216.4	0.0
212.3	213.0	214.8	216.4	0.0
213.4	214.1	216.1	217.8	0.0
214.8	215.6	217.8	219.5	0.0
216.9	217.8	220.2	222.2	0.0
219.8	220.8	223.6	225.9	0.0
197.8	198.6	201.0	203.9	0.0
197.7	198.5	201.0	203.8	0.0

197.8	198.6	201.1	203.9	0.0
199.1	199.9	202.5	205.5	0.0
200.7	201.7	204.5	207.7	0.0
203.0	204.1	207.2	210.8	0.0
206.2	207.4	211.0	215.0	0.0
188.2	189.4	192.8	0.0	0.0
188.1	189.3	192.8	0.0	0.0
188.4	189.6	193.1	0.0	0.0
189.8	191.1	194.8	0.0	0.0
191.6	193.0	197.0	0.0	0.0
194.2	195.7	200.2	0.0	0.0
0.0	0.0	0.0	0.0	0.0
181.9	183.9	190.4	0.0	0.0
181.7	183.8	190.3	0.0	0.0
182.3	184.3	190.9	0.0	0.0
183.9	186.1	193.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
178.3	182.6	0.0	0.0	0.0
178.1	182.4	0.0	0.0	0.0
179.0	183.3	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
177.4	0.0	0.0	0.0	0.0
177.1	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
349.0	350.2	353.5	355.5	357.9
348.1	349.4	352.6	354.7	357.0
350.9	352.2	355.4	357.5	359.8
360.7	362.0	365.4	367.6	370.1
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
319.8	321.4	325.4	328.5	0.0
320.9	322.4	326.5	329.6	0.0
325.5	327.0	331.0	334.2	0.0
337.0	338.6	342.9	346.4	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
302.3	304.2	309.4	314.4	0.0
305.3	307.2	312.4	317.7	0.0
312.3	314.1	319.4	325.1	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0

289.5	292.C	299.2	C.0	0.C
295.4	297.9	305.3	U.0	0.C
305.3	308.C	315.7	0.0	0.0
C.C	0.C	0.0	0.0	0.C
C.C	0.C	0.0	0.0	0.C
C.C	0.C	0.0	0.0	U.0
C.C	0.C	0.0	0.0	0.0
284.6	288.5	300.4	0.0	0.C
294.1	298.4	311.8	0.0	0.C
C.C	0.C	0.0	0.0	0.C
C.C	0.C	0.0	0.0	0.0
C.C	0.C	0.0	0.0	0.C
C.C	0.C	0.0	0.0	0.C
C.C	0.C	0.0	0.0	0.0
287.2	294.8	0.0	0.0	0.0
C.C	0.C	0.0	0.0	0.C
C.C	0.C	0.0	0.0	0.C
C.C	0.C	0.0	0.0	0.0
C.C	0.C	0.0	0.0	0.C
C.C	0.C	0.0	0.0	0.C
C.C	0.C	0.0	0.0	0.C
C.C	0.C	0.0	0.0	0.0
C.C	0.C	0.0	0.0	0.0
C.C	0.C	0.0	0.0	0.C
C.C	0.C	0.0	0.0	0.C
C.C	0.C	0.0	0.0	0.0
C.C	0.C	0.0	0.0	0.0
C.C	0.C	0.0	0.0	0.C
C.C	0.C	0.0	0.0	0.C
C.C	0.C	0.0	0.0	0.0
C.C	0.C	0.0	0.0	0.C
C.C	0.C	0.0	0.0	0.C
C.C	0.C	0.0	0.0	0.C
C.C	0.C	0.0	0.0	0.C
C.C	0.C	0.0	0.0	0.0

VITA

VITA

Salim S. Hejal was born on January 19, 1945 in Beirut, Lebanon. He received his primary and secondary education in that city and graduated from International College in June 1962. He then attended the American University of Beirut from 1962 to 1966 where he studied Civil Engineering. He obtained his BE (distinction) in June 1966 and received honors.

In September 1966 Mr. Hejal entered Purdue University to pursue graduate work in Transportation Engineering and obtained an MSCE in June 1967. He stayed at Purdue University to complete the requirements for the Ph.D. degree joining the staff as a research and teaching graduate instructor. In the fall of 1968 he transferred to the School of Industrial Engineering to receive an MSIE in January 1969.

Mr. Hejal is a member of Order of Engineers and Architects in Beirut, Lebanon, a supporting member of the Highway Research Board, a junior member of the Institute of Traffic Engineers, a member of Tau Beta Pi Engineering Honorary and an associate member of Sigma Xi Research Honorary. Mr. Hejal is a Lebanese citizen.